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FUEL ECONOMY AND EXHAUST EMISSIONS CHARACTERISTICS OF DIESEL VEHICLES: TEST RESULTS OF A PROTOTYPE FIAT 131 NA 2.4 LITER AUTOMOBILE

S.S. Quayle, M.M. Davis, and R.A. Walter

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142

MAY 1981

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Cleveland OH 44135
Under Interagency Order C-32817-D

for
U.S. DEPARTMENT OF ENERGY
Conservation and Solar Applications
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16. Abstract
This report documents the results obtained from fuel economy and emission tests conducted on a prototype Fiat 131 naturally-aspirated diesel vehicle. The vehicle was tested on a chassis dynamometer over selected drive cycles and steady-state conditions. Two fuels were used, a U.S. #2 diesel and a European diesel fuel. The vehicle was tested with retarded timing and with and without an oxidation catalyst. Particulate emission rates were calculated from dilution tunnel measurements and large volume particulate samples were collected for biological and chemical analysis. It was determined that while the catalyst was generally effective in reducing hydrocarbon and carbon monoxide levels, it was also a factor in increasing particulate emissions. Increased particulate emission rates were particularly evident when the vehicle was operated on the European fuel which has a high sulfur content.

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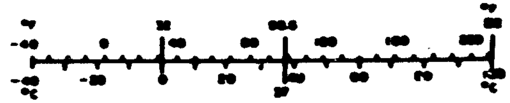
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



1. INTRODUCTION

Under Interagency Order C-32817-D, the Department of Transportation, Transportation Systems Center (DOT/TSC) participates in a cooperative research program with the Department of Energy. NASA Lewis Research Center is the managing organization. The objectives of this project are two-fold:

1. To determine the ability of various diesel technologies to improve fuel efficiency and reduce exhaust emissions and
2. To collect adequate particulate samples for chemical and biological characterization as part of the DOE Diesel Health Effects Research Program.

The vehicle used for the portion of the program discussed in this paper was a naturally aspirated Fiat prototype diesel. This vehicle was loaned to TSC by Fiat through contract DOT-TSC-1424. As part of this DOT contract, Fiat provided an extensive data base on light-weight automotive diesel power plants in the 50 to 100 hp range, in vehicle inertia weights from 2000 to 3000 pounds. Current diesel technology, advanced vehicle concepts, fuel economy, emissions, and performance were integrated into the data base.[1]

The Fiat 131 NA (rated 70hp at 4200rpm) was tested at the DOT/TSC Automotive Research Laboratory in a 3000-lb inertia weight configuration (Figure 1). The vehicle was equipped with a 2.4-liter, indirect injection engine and five-speed manual transmission. It was tested over selected drive cycles and steady-state conditions on a large-roll, chassis dynamometer. The test cycles included the EPA/Federal Test Procedure urban cycle (FTP), the Highway Fuel Economy Test cycle (HFET), the Congested Urban Expressway cycle (CUE), and the New York City cycle (NYCC). Steady-state measurements were collected at six different speed-gear combinations. Approximately 81 grams of particulate matter were collected and sent to Lovelace Inhalation Toxicology Research Institute for inclusion in the DOE Diesel Health Effects Research Program. (The various samples and cycles are given in Table A-6.) The results of the

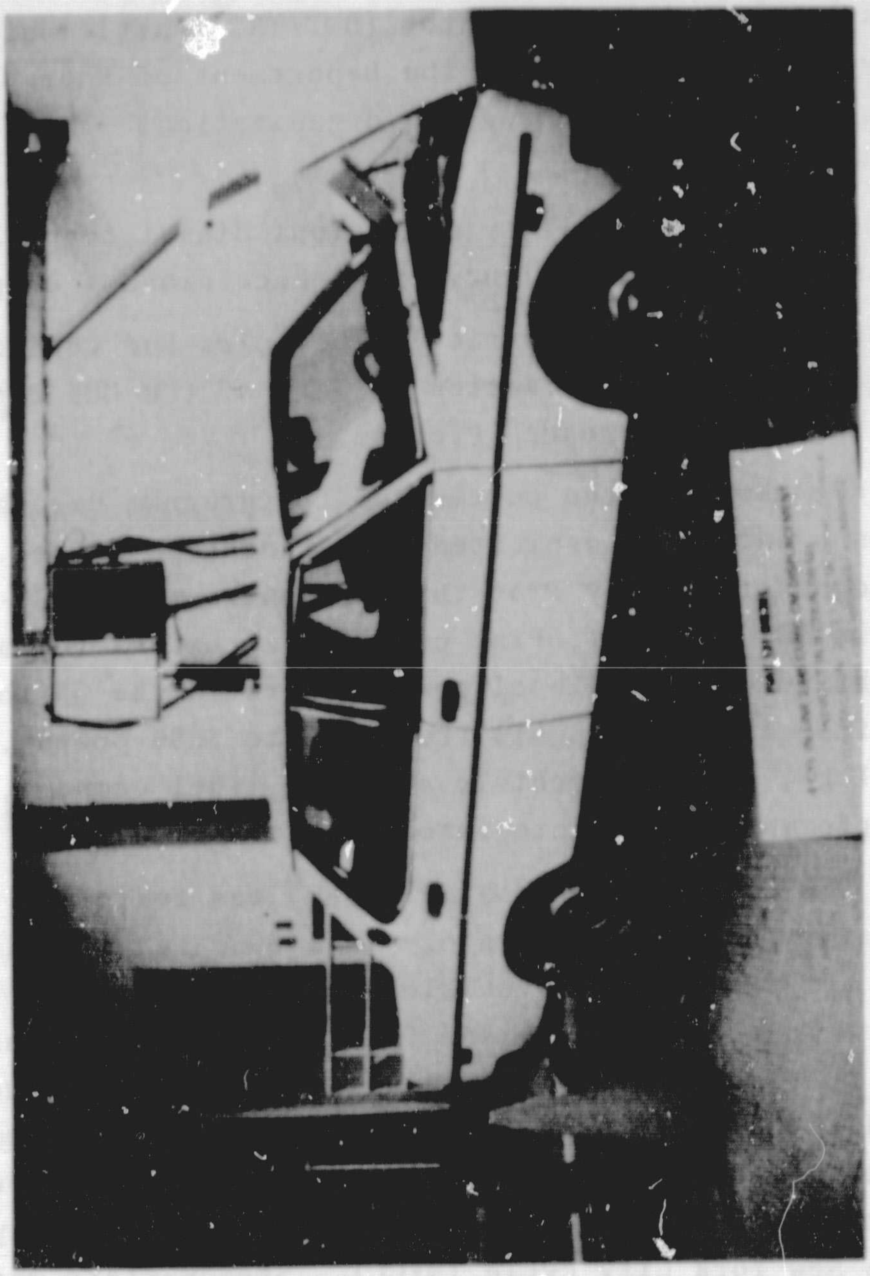


FIGURE 1. FIAT 131 NA DIESEL IN A 3000 LB INERTIA VEHICLE

study on the chemical and biological characterization of diesel particulates conducted by Lovelace ITRI will be published in a separate document.

2. EXPERIMENTAL DESIGN

2.1 TEST VEHICLE

This section describes the salient features of the Fiat 131. For a more detailed description, reference should be made to the Fiat report.[2]

2.1.1 Engine and Vehicle Specifications

The engine, a 2.4-liter prototype indirect injection diesel rated at 70 hp (51 kW) at 4200 rpm, is one of the Fiat Sofim family of 3, 4, and 6 cylinder engines. The main engine specifications are given in Table 1.

The vehicle's inertia weight is 3000 pounds. Its frontal area is 1.83 m^2. Tire size is 185/70-13. The Fiat 131 vehicle is equipped with a five-speed manual transmission. The gear ratios are 3.612, 2.045, 1.357, 1.000 and 0.870; the axle ratio is 3.20.

2.1.2 Manufacturer's Data on Emissions, Fuel Economy, and Performance

The 0-60 mph acceleration time as determined by the manufacturer is 18.1 seconds. The emissions rates, as determined by the manufacturer, are as follows: without oxidation catalyst 0.31/1.68/1.60/0.55 grams per mile of HC/CO/NO_x/particulate; with catalyst, 0.36/0.33/1.01/1.25 grams/mile of HC/CO/NO_x/particulate respectively. The manufacturer-determined combined urban and highway fuel economy is 34.6 mpg.

2.1.3 Catalyst

The catalyst was a monolithic oxidation prototype manufactured by Johnson-Matthey. The catalyst loading was 120 grams of platinum per cubic foot or 3.93 grams of platinum per catalyst. When the catalyst was added to the vehicle, the fuel injection timing was retarded approximately 5° to facilitate NO_x control. Nitric oxide formation is proportional to combustion temperature; retarding static injection timing (SIT) lowers the peak combustion temperature because the ignition delay is shortened, (the fuel is injected

TABLE 1.

TABLE 1. ENGINE CHARACTERISTICS

4-Cylinder Fiat 131, Indirect Injection

Bore	93 mm
Stroke	90 mm
Stroke/Bore	0.97
Total Displacement	2445 cm^3
Compression	22:1
Maximum Power	70 hp at 4200 rpm
Maximum Torque	14.4 kg-m (141Nm) 2400 rpm
Combustion System	Indirect Injection (Comet V)
Fuel Injection Pump	Rotary Bosch, VE 4/9
Plunger Diameter	9 mm
Static Injection Timing (at 1 mm plunger lift)	1° C.A. BTDC

at higher temperatures and pressures, but less is injected before ignition), and less fuel evaporates and mixes in the lean flame region where NO is normally formed at high local concentrations. An additional benefit of retarded timing is that mechanical and thermal stresses and noise are normally lowered.

Shortened residence times and lower temperatures, however, tend to make the completion of oxidation and combustion processes less likely. Thus hydrocarbon, carbon monoxide, and particulate levels generally increase with retarded timing. It was anticipated that these increases in HC and CO levels due to timing retardation would be compensated for by the presence of an active oxidation catalyst. Data on the overall effect on the particulate levels was limited and inconclusive. It was anticipated, however, that, particulate sulfates would be produced by the interaction of the fuel sulfur and the catalytic surface.

It should also be noted that catalytic converters such as the one employed in this test series are effective only when heated to some operating temperature. These devices have thermal inertia; the magnitude being design dependent. This catalyst did not appear to "light off" or become active until an inlet temperature of approximately 360-400^{o}F was obtained. Generally, at low speeds and/or low loads, the catalyst is inactive. (See Figure 2.)

2.1.4 Fuel

Two fuels were used in the test series conducted by DOT/TSC. One fuel was provided by the Environmental Protection Agency and is hereafter cited as EPA fuel; the other fuel was provided by Fiat and is hereafter cited as European (or Eur) fuel.

The EPA fuel was taken from a common lot that has been used in other test vehicles to generate particulate samples for the EPA Diesel Health Effects Research Program. The fuel analyses are given in Table 2. The EPA test fuel has a high specific gravity and relatively low cetane index; this tends to slightly increase the specific fuel consumption (g/hp-hr). Environmental

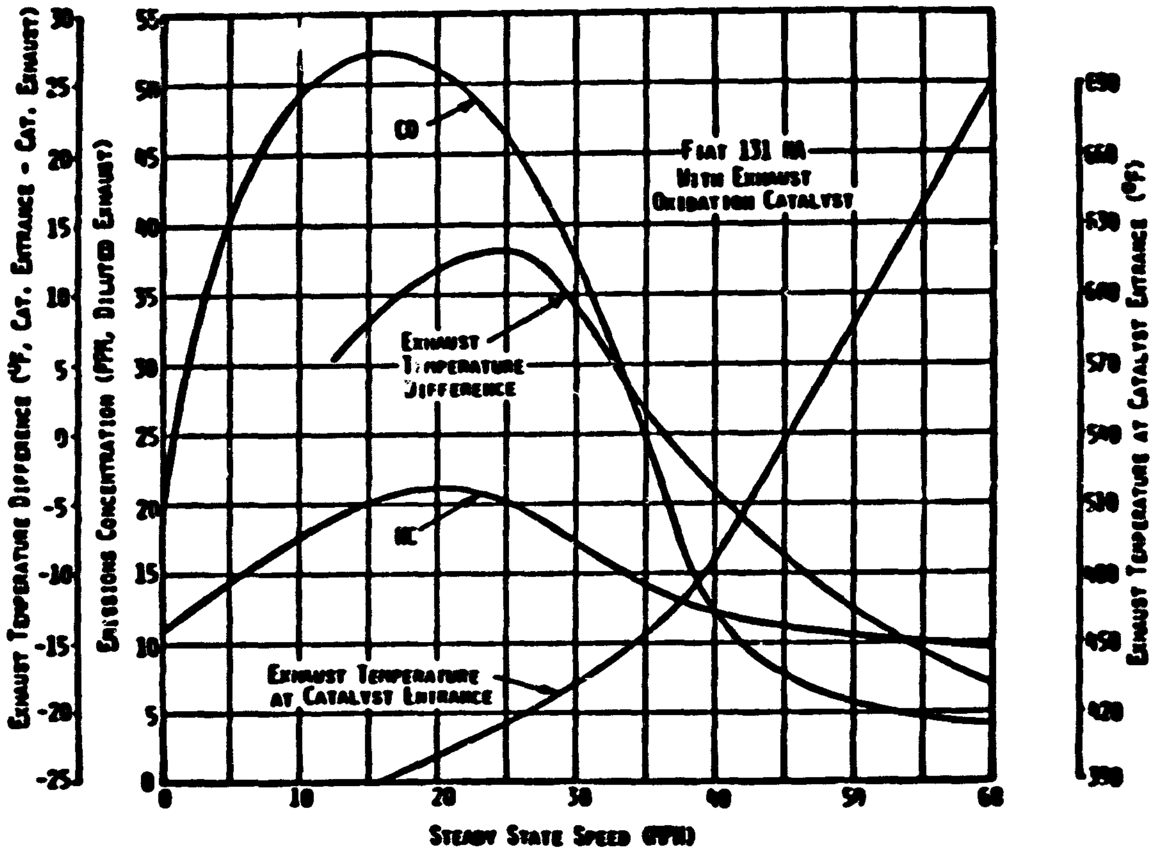


FIGURE 2. EMISSIONS AND TEMPERATURE VS. STEADY STATE SPEED

TABLE 2. DIESEL FUEL CHARACTERISTICS[3]

	EPA #2 Diesel	European Diesel	Test Method
Hydrogen Ratio	1.79	1.92	Calculation based on atomic weight.
Specific Gravity	0.8488	0.836	ASTM D1298-67.
BTU/lb	19,541	19,572	ASTM 240-76.
BTU/gallon	138,116	135,888	ASTM 240-76.
Hydrogen, %	13.03	13.64	Pregl modified Ingram technique
Carbon, %	86.75	84.68	Pregl modified Ingram technique
Sulfur, %	0.25	0.77	ASTM D1552-64.
Cetane Index	48.5	56.5	ASTM 0976-66.
Distillation Range °F			ASTM D86.
IBP	387	371	
10%	430	423	
50%	509	520	
90%	599	631	
End Point	652	689	
Recovery, %	98.5	99.0	

Protection Agency/Research Triangle Park reports that the fuel has a mid-range aromatic content tending to increase smoke emissions slightly and lower the cetane index. The sulfur content of the EPA fuel (0.25%) is typical of an ASTM Grade 2-D fuel. In contrast, the European diesel fuel has both a higher cetane index and higher sulfur content (0.77%).

2.2 TEST EQUIPMENT

This section briefly describes the test equipment and the gaseous and particulate measurement techniques.

2.2.1 Dynamometer

The DOT/TSC chassis dynamometer is a fully programmable direct-current machine with a single,50-inch diameter roll. The features of this dynamometer are shown in Table 3. It can simulate individually, and in combination, loads due to rolling losses, aerodynamic drag, vehicle inertia, uphill and downhill grades, and road-speed air-flow. Both rear wheel and front wheel drive vehicles can be accommodated. Maximum ratings of the dynamometer are 315 hp, 6400 pound-ft torque, 105 mph, 5000-pound axle load, and air speeds to 72 mph. Test cell temperature is normally controlled at 74° ± 5°F. Vehicle inertia can be electrically simulated by the digital logic and electrical control, or mechanically via flywheels. For the tests conducted on the Fiat 131, electrical simulation of inertia was used.

Coast-down data was supplied by Fiat for the test vehicle. The experimentally derived settings for the prototype Fiat were empirically modified to duplicate the curve supplied by the manufacturer. The dynamometer was programmed to fit the curve through the use of the following torque equation:

$$T = RW + BWV + CV^2 + GW + M \frac{dv}{dt}$$

where:

T = dynamometer torque

R = constant wheel rolling resistance (function of tire type, inflation pressure, etc.)

TABLE 3. DIRECT CURRENT CHASSIS DYNAMOMETER SPECIFICATIONS

- SINGLE AXIS, LARGE (50-INCH DIAMETER) ROLL (400 PEVOLUTIONS/MILE)
- MAXIMUM TORQUE, SPEED: 6400 LB-FT, 0-39 MPH
- MAXIMUM POWER, SPEED: 315 HP, 39-105 MPH
- TORQUE SENSITIVITY: ±1.3 LB-FT (0.02% FULL SCALE)
- CORRESPONDING TRACTIVE FORCE AT WHEELS: ±0.61 LB
- DUAL TORQUE LOAD CELLS, 150% AND 15% OF FULL SCALE
- SIMULATED ROAD-SPEED AIR FLOW: 0-72 MPH
- MAXIMUM DRIVE-AXLE LOAD CAPACITY: 5000 LB
- MECHANICAL INERTIA OF SYSTEM EQUIVALENT TO VEHICLE WEIGHT OF 1800 LB
- ELECTRICAL SIMULATION OF VEHICLE WEIGHT FROM 1200 LB TO 7000 LB
- MECHANICAL SIMULATION OF VEHICLE WEIGHT FROM 1800 LB TO 8750 LB
- DIGITAL TORQUE CONTROL SYSTEM, PROGRAMMABLE TO SIMULATE -
    - ROLLING AND AERODYNAMIC LOSSES
    - VEHICLE INERTIA
    - POSITIVE AND NEGATIVE GRADES
    - HEAD AND TAIL WINDS
- ADJUSTABLE CONSTANT-SPEED CONTROL
- FULL DRIVE-CYCLE CAPABILITY

W = vehicle weight

B = speed-proportional component of rolling resistance

V = instantaneous speed

C = aerodynamic drag

G = road slope (i.e., ± grade)

M = vehicle effective mass

$\frac{dv}{dt}$ = instantaneous acceleration

The road slope was zero for all of the tests presently under discussion. The dynamometer settings and coast-down curve for the Fiat 131 NA vehicle are given in Figure 3.

2.2.2 Gaseous Emission Measurements

All measurements of gaseous hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), and carbon dioxide (CO_2), were performed using a 325-cfm Constant Volume Sampling (CVS) System with a Critical Flow Orifice (CFO) (Figure 4). The instrumentation and procedures employed were those designated by EPA.[4] The instrumentation included non-dispersive infrared (NDIR) CO and CO_2 analyzers, a chemiluminescence NO_x analyzer, and a heated flame ionization detector (HFID) (Table 4). Gaseous emission samples were collected in and analyzed from Tedlar bags (with the exception of HC). The HC sample was taken from the dilution tunnel in real-time via heated lines (380°F). The electronic output signal of the HC analyzer was integrated over the test interval. All instrumentation was calibrated with ± 2% calibration gases before each gas sample was analyzed. Additionally, each instrument was calibrated over its useful range at 8 calibration points. The hot FID and its sampling system was the instrument that required the most maintenance. To insure the integrity of this system, routine leak checks were performed on the internal and external heated parts.

Dynamometer Settings

Speed Independent	- 7000 newton/kg
Speed Dependent	- 1000 newton/kg/km/hr
Windage	- 0.0418 (newton/km/hr)^2
Vehicle Weight	- 1361 kg
System Mech. Wt.	825 evw/kg
Manual Torque	0 newton-meter
Crade	- 0%

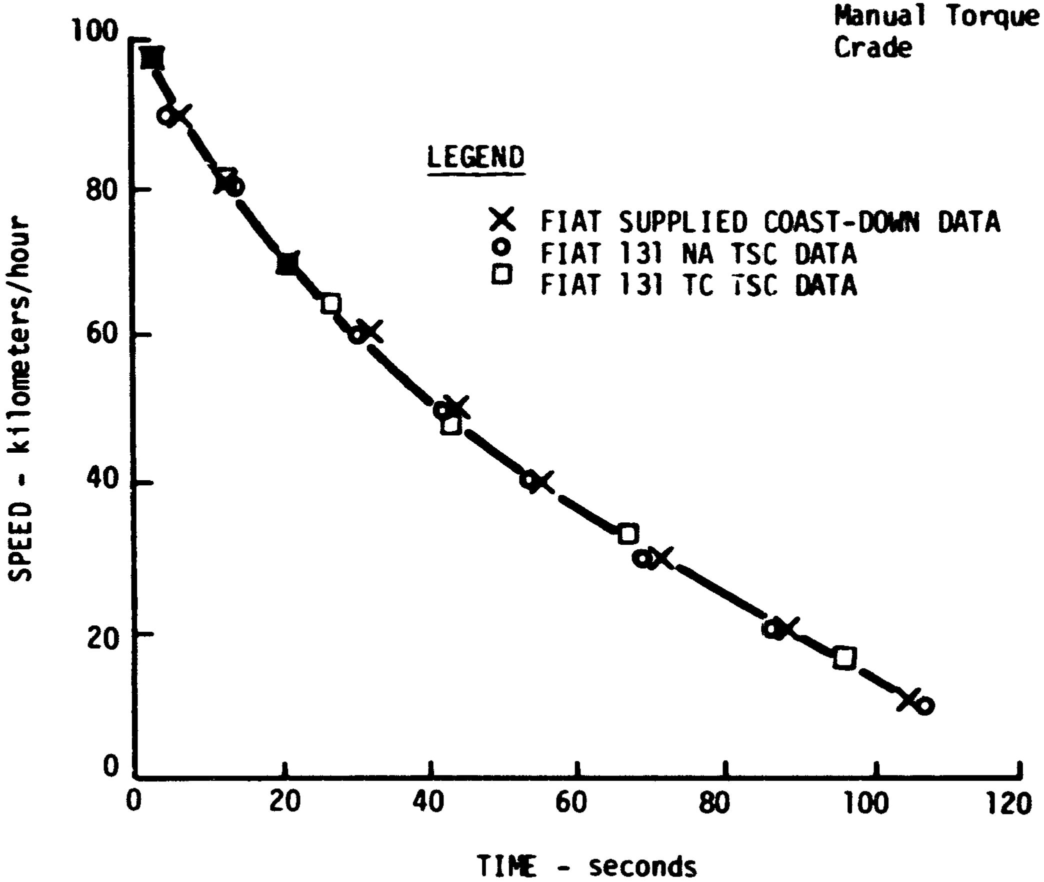


FIGURE 3. FIAT 131 COAST-DOWN CHARACTERISTICS

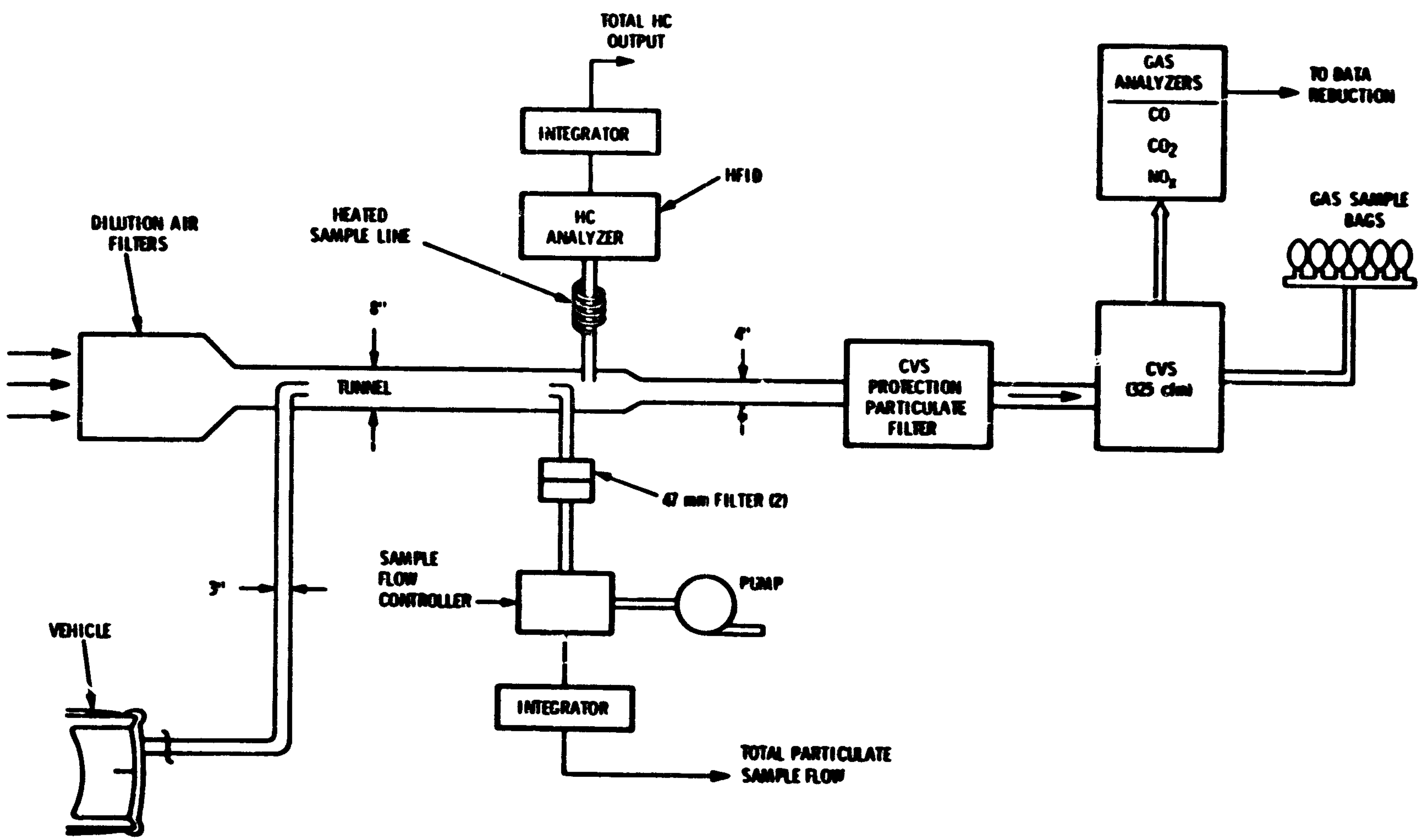


FIGURE 4. AUTOMOTIVE RESEARCH LABORATORY, PARTICULATE/GAS SAMPLING SYSTEM (CHARACTERIZATION)

TABLE 4. GASEOUS EXHAUST EMISSION INSTRUMENTATION

Exhaust Species	Method	Model Number
Hydrocarbon	Heated Flame Ionization Detector	Scott 215 Beckman 402
Carbon Monoxide	Non-Dispersive Infrared (NDIR)	Horiba A1A-21 (AS) low range; MSA 202 high range
Nitrogen Oxides	Chemiluminescence with Thermal Converter	Scott 125
Carbon Dioxide	NDIR	MSA 202

Calibration Gases: ± 2% National Bureau of Standards, Traceable.

The bulk exhaust stream was filtered upstream of the CVS to minimize the effect of particulate matter build-up in the CVS-CFO, which produced a subsequent drop in flow. Gaseous measurements were performed before and after the filter box to assure that the filter medium had no effect on the gas sample. The sampling system was checked periodically by propane injection whenever the system was modified or reassembled. Agreement between the measured propane mass and the injected mass was maintained at $\pm 3\%$.

2.2.3 Particulate Emission Measurements

Particulate mass measurements were performed using a dilution tunnel and the EPA recommended procedures for light-duty diesel vehicles.[4] The 8-inch diameter tunnel and its associated hardware are shown schematically in Figure 4. Tunnel specifications are listed in Table 5; particulate sampling instrumentation is indicated in Table 6.

To determine particulate mass (grams per mile), a sample of the diluted exhaust was extracted from the bulk-stream tunnel flow at a point which was 11 tunnel diameters downstream of the vehicle exhaust injection. The particulate sample probes were 1-inch diameter stainless steel. The filter medium used was 47 mm Pallflex T60A20 teflon-coated fiberglass held in Millipore model I quick-release holders. The flow through this system was controlled by a Tylan mass flow controller (Model FC202) at 10 L/min.

For the substantial amounts of particulate matter needed for the EPA Diesel Health Effects Research Study, 20-inch x 20-inch Pallflex type T60A20 filters were used. These filters were mounted in parallel in two filter holders (Figure 5) that sampled approximately 25% of the exhaust stream after the dilution tunnel. All large and small filters were stored in a temperature and humidity controlled weighing room prior to sample collection. The small filters were weighed on a Cahn Model G Electrobalance with a 1 microgram sensitivity. The 20-inch x 20-inch filters were weighed on a Mettler P-1200 pan balance with a sensitivity of 0.01 gram which had been modified to accept the large filters. The weighing of large filters

TABLE 5. EXHAUST DILUTION TUNNEL SPECIFICATIONS

Diameter	8 inches
Minimum Active Length*	75 inches
Minimum Residence Time	0.42 sec. @ 325 cfm
Material	Stainless Steel
Air Filters	
Prefilter	Cambridge Model 3CP60
Hydrocarbon Filter	Cambridge Activated Carbon Model 5FB45
Absolute Filter	Cambridge Model 13-1000-1
Connecting Tubing - vehicle to tunnel	3-inch stainless steel smooth-wall and silastic flexible couplings
Connecting Tubing - tunnel to CVS	4-inch flexible stainless steel and Marmon couplings

*Distance from vehicle exhaust exit to nearest sampling port.

TABLE 6. EXHAUST PARTICULATE SAMPLING AND MEASUREMENT INSTRUMENTATION

Characterization	
Sample Probes	1 in. diam. stainless steel
Filter Holder	Millipore 47 mm
Filter Medium	Pallflex T60A20 Fluoropore
Sample Flow Control	Tylan Mass Flow Controller Model FC202 and FMT-3 electronics unit Model FMT-3 Integrator
Scale	Cahn Electrobalance, Model G
Large Volume Collection	
Filter Medium	Pallflex T60A20 20" x 20"
Sample Flow Control	PDP pumped sample of approx. 100 cfm
Scale	Mettler P1200 (Modified)

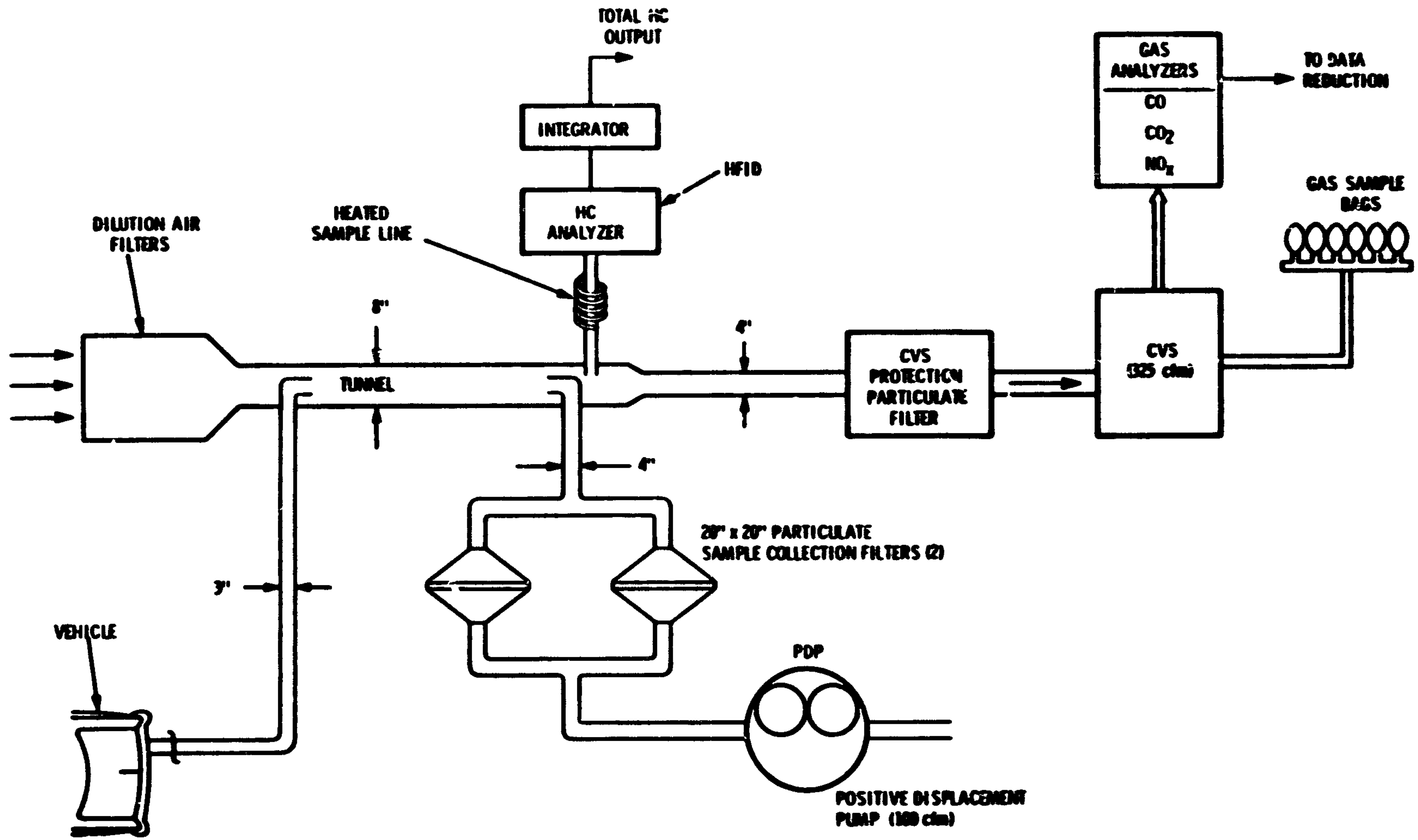


FIGURE 5. AUTOMOTIVE RESEARCH LABORATORY, PARTICULATE/GAS SAMPLING SYSTEM (LARGE SCALE PARTICULATE COLLECTION)

was performed in an "unventilated" chemical hood to eliminate the effects of air currents. All balances were calibrated at least daily. After collections, the filters were allowed to stabilize in the weighing room prior to reweighing. They were considered to be temperature and humidity stabilized when the net weight changed less than 1% over two minutes. After weighing, filters were placed in Tedlar envelopes and placed in dark freezer storage (approximately -20°C) as is recommended by EPA during shipment for chemical and biological characterization. Figures 6 through 8 illustrate various procedures in the exhaust particulate sampling and handling.

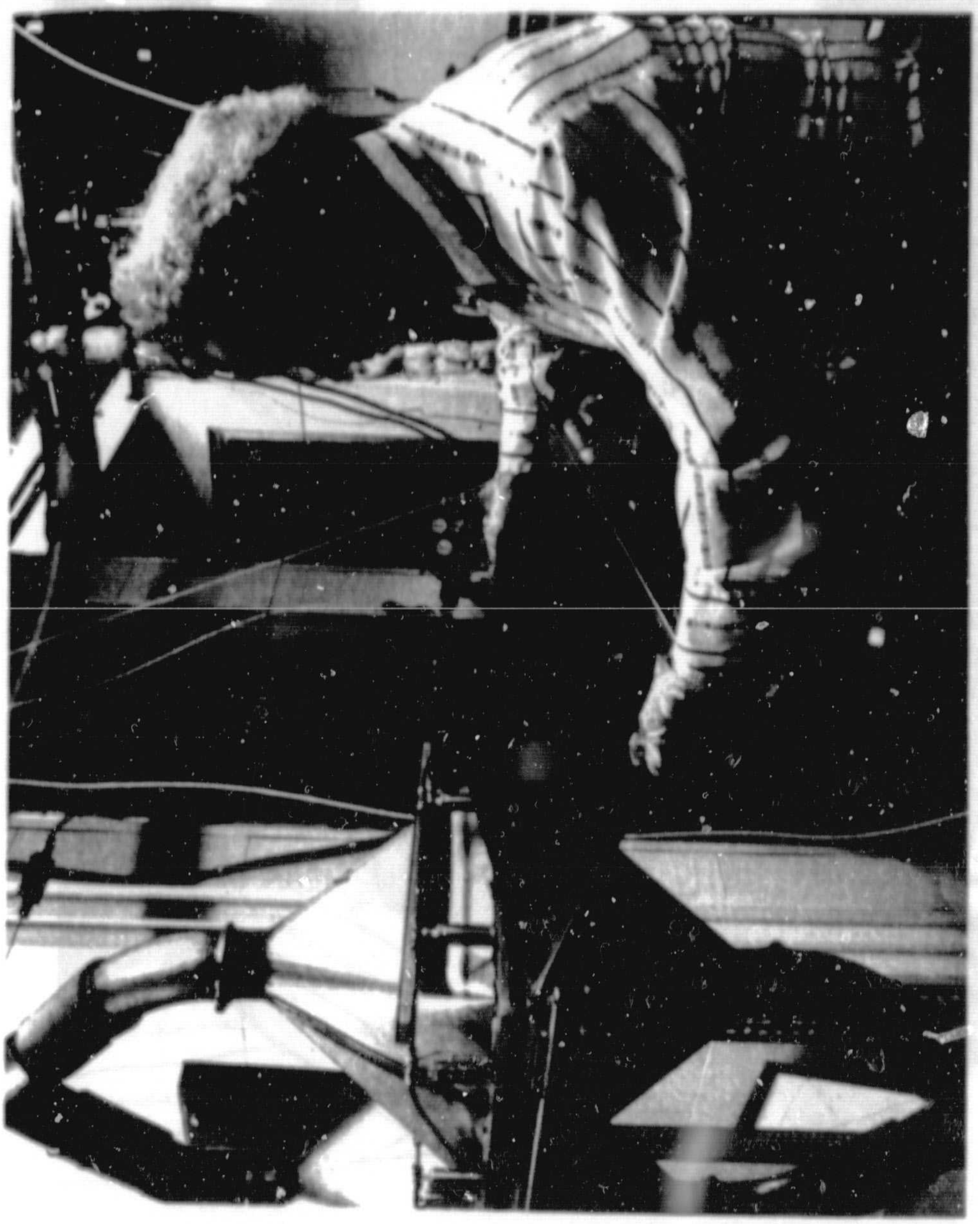


FIGURE 6. REMOVING 20"x20" FILTER FROM HOLDER

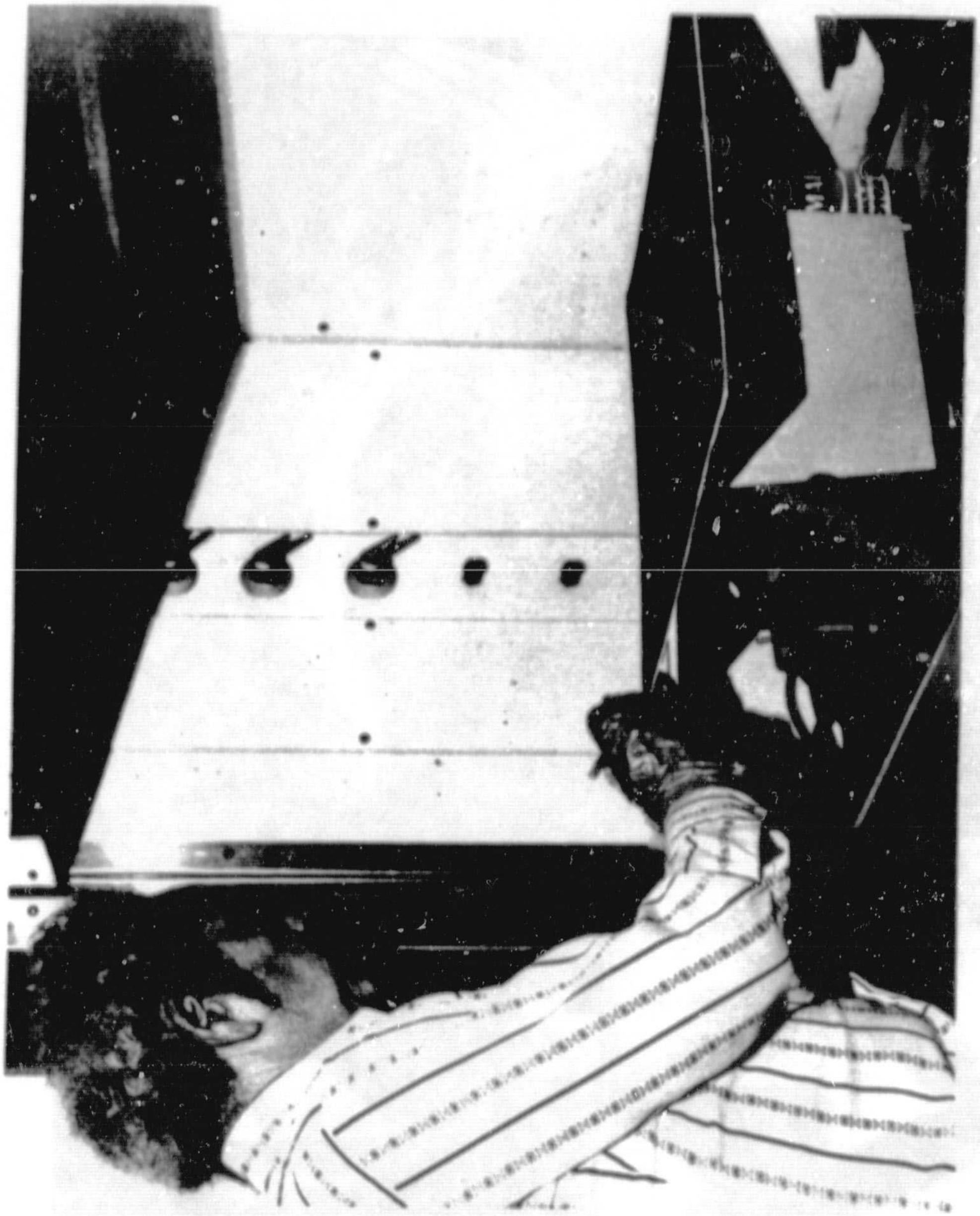


FIGURE 7. WEIGHING 20"x20" FILTER

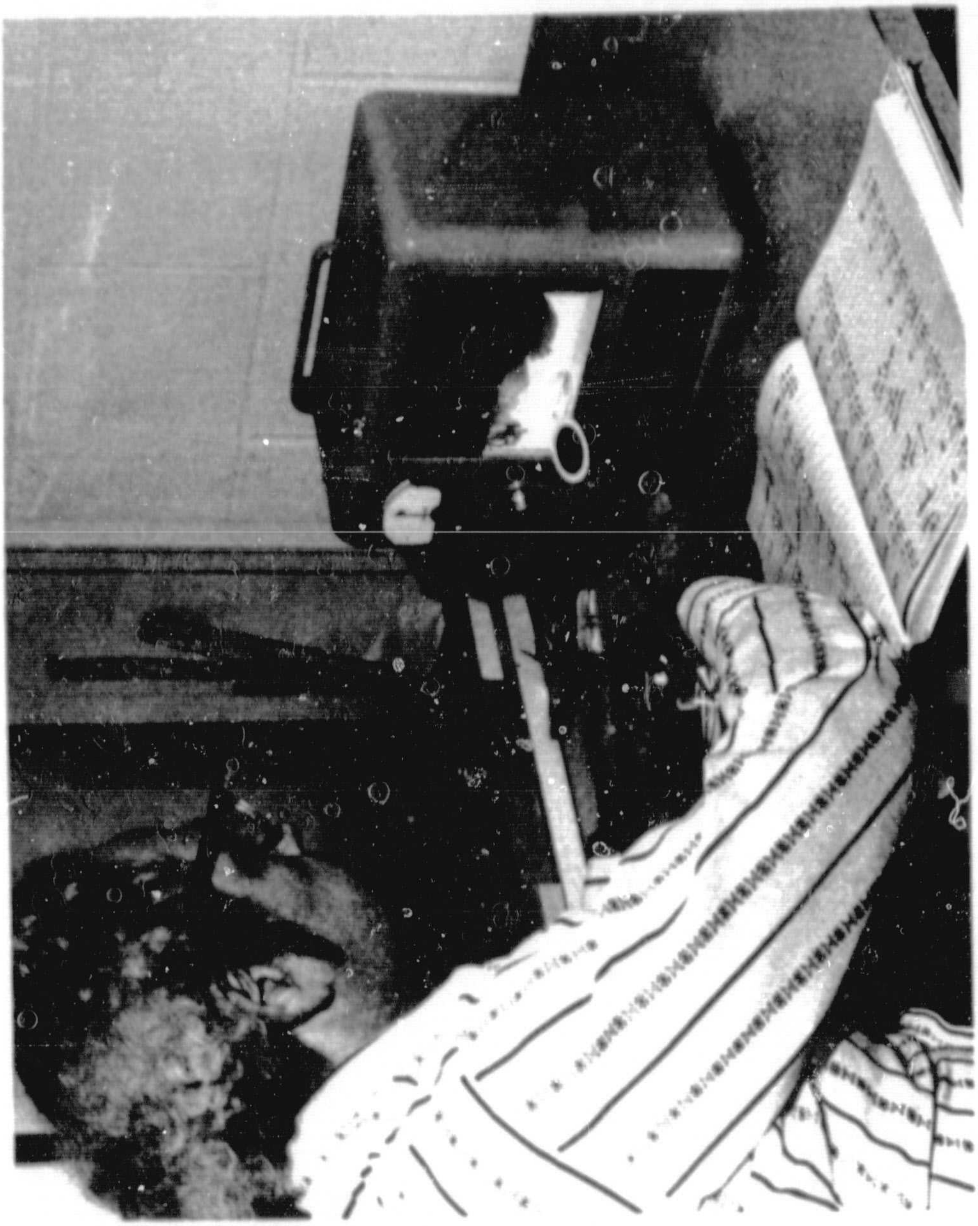


FIGURE 8. WEIGHING 47mm FILTER

3. TEST PROCEDURES

3.1 GENERAL

The laboratory test procedures used for determining the gaseous and particulate emissions rates and the fuel economy of the Fiat 131 NA diesel were those prescribed by the U.S. Environmental Protection Agency. Two types of testing were conducted:

- Characterization tests to determine the gaseous and particulate emission rates and fuel economy
  and
- Large-volume sampling tests during which large amounts of diesel exhaust particulates were collected on 20-inch x 20-inch filters for chemical and biological analyses.

3.2 DRIVE CYCLES

The vehicle was tested on the TSC Automotive Research Laboratory chassis dynamometer using various steady-state speeds and transient drive cycles. The characterization tests included the EPA Federal Test Procedure urban drive cycle (FTP), the EPA/Highway Fuel Economy Test (HFET), the Congested Urban Expressway cycle (CUE), and the New York City Cycle (NYCC). Characterization tests were also performed at steady-state speeds of 15 mph in first gear, 25 mph in second gear, 40 mph in third gear, 50 mph in fourth and fifth gears, and 60 mph in fifth gear. These steady-state tests are hereafter referred to as 15 mph/1st gear, 25 mph/2nd gear, 40 mph/3rd gear, etc. Table 7 summarizes the characteristics of the four transient test cycles. Only transient test cycles were used for the large-volume sampling tests.

Steady-state tests were conducted for a time period of 400 seconds. Thus the steady-state emissions rates and fuel economy values are 400-second averages.

TABLE 7. DRIVE CYCLE CHARACTERISTICS

Cycle	Distance (miles)	Avg Speed (mph)	Time (sec)	Remarks
Federal Test Procedure (FTP)	11.1	21.6	1877	Composite
- Bag 1	3.6	25.6	505	Cold Start
- Bag 2	3.9	16.2	867	Stablized
- Bag 3	3.6	25.6	505	Hot Start
Highway Fuel Economy Test (HFET)	10.2	48.2	765	Hot Start
Congested Urban Expressway - Sulfate (CUE)	13.3	34.2	1398	Hot Start
New York City Cycle (NYCC)	1.1	6.6	598	Hot and Cold Starts

3.3 CHARACTERIZATION TESTS

3.3.1 Vehicle Preparation

The prototype Fiat 131 NA diesel vehicle was prepared for testing in the following manner. Rear tire pressure was checked daily and set to 32 psig. The vehicle was soaked a minimum of 12 hours at a cell temperature between 68°F and 86°F prior to the initiation of cold start FTP tests. For all tests the dynamometer was brought to operating temperature in the motoring mode.

3.3.2 Vehicle Dynamometer Matching

As previously mentioned (Section 2.2.1) the initial chassis dynamometer settings were determined from actual vehicle coast-down data supplied by Fiat. The dynamometer settings were then adjusted empirically until the measured coast-down, speed-time values duplicated those of the supplied data.

3.3.3 Engine Starting

For cold-start tests, the engine's glow-plugs were activated. Cranking was initiated when the dashboard lamp indicated that the engine was ready for starting. In general, the FTP cycle was the first test of the day and was followed by any number of subsequent hot-start tests. If between tests the engine was allowed to cool down, it was returned to operating temperature by running the vehicle at a steady speed point until the dashboard oil temperature indicator was stabilized: the warm-up time required was normally 15 to 20 minutes.

All transient test cycles were conducted by requesting the driver to follow the pre-printed speed-time trace on a strip chart recorder. The driver was required to duplicate the speed-time profile within ± 2%. Steady-state speeds were determined by the vehicle speedometer and were checked against the dynamometer-indicated roll speed.

3.3.4 Sample and Data Acquisition

Gaseous and particulate exhaust emissions samples were obtained using EPA regulation guidelines as described in Sections 2.2.2 and 2.2.3.

3.3.5 Data Reduction

The data was reduced using EPA procedures outlined in the Federal Register.[4] Grams per mile (g/mi) of the selected emission constituents and miles per gallon (mpg) were calculated for each test condition.

4. RESULTS

4.1 GENERAL

The Fiat 131 NA vehicle tests included four cyclic test drives and six steady-state tests detailed in Section 3.2. At least three duplicate runs were made for each test point and condition. The four test conditions consisted of the following:

- the vehicle run on European fuel while equipped with an oxidation catalyst, (hereafter designated as cat./Eur.);
- the vehicle run on European fuel, without catalyst, (designated as no cat./Eur.);
- the catalyst-equipped vehicle run on EPA fuel (cat./EPA),
- and without catalyst (no cat./EPA).

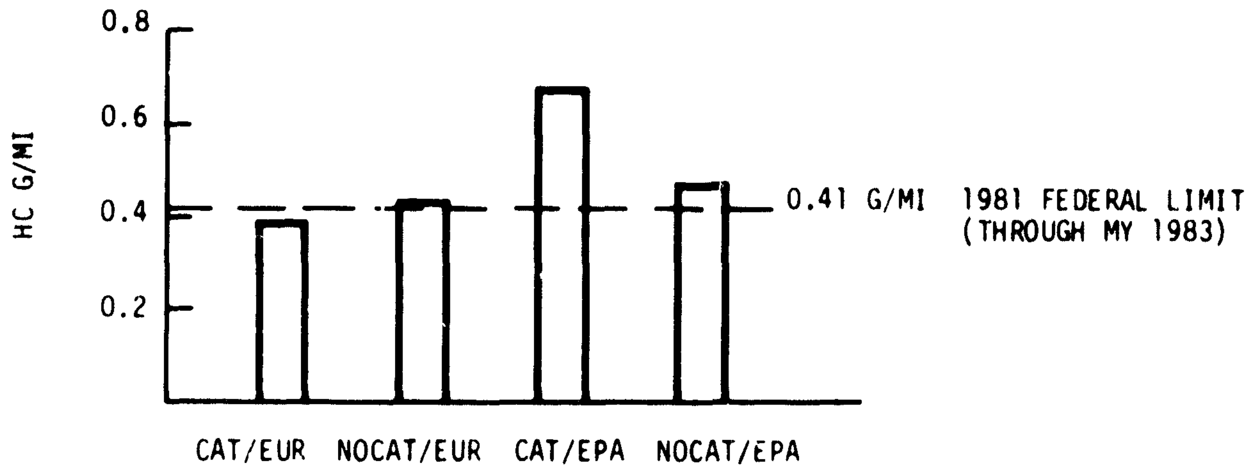
The test matrix is shown in Figure 9.

4.1.1 Results and Federal Emissions Limits

According to the results of these tests, the Fiat 131 NA vehicle was unable to meet the 1981 Federal Emissions Standards of 0.41/3.4/1.0 g/mi of $HC/CO/NO_x$ respectively. As is shown in Figure 10, the vehicle most nearly met these standards when it was equipped with a catalyst and run on European fuel. In this test configuration its g/mi emissions of $HC/CO/NO_x$ were 0.39/0.66/1.05. The NO_x standard, however, may be waived on EPA's authority to 1.5 g/mi for model years 1981 to 1984. With such a waiver, the catalyst equipped vehicle run on European fuel meets 1981 emission limits. It is necessary, however, to design prototype vehicles to emission levels below those of the standards due to prototype-to-certification slippage, car-to-car variability, test-to-test variability and deterioration factors. EPA has stated that a margin of 20 percent is adequate. The hydrocarbon emissions fall short of the 20% margin.[4]

TEST POINT \ TEST CONFIGURATION	CATALYST/ EUROPEAN FUEL	NO CATALYST/ EUROPEAN FUEL	CATALYST/ EPA FUEL	NO CATALYST/ EPA FUEL
FTP	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
HWY	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
CUE	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
NYCC	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
15 MPH/1ST GEAR	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
25 MPH/2ND GEAR	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
40 MPH/3RD GEAR	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
50 MPH/4TH GEAR	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
50 MPH/5TH GEAR	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
60 MPH/5TH GEAR	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐

FIGURE 9. TEST MATRIX



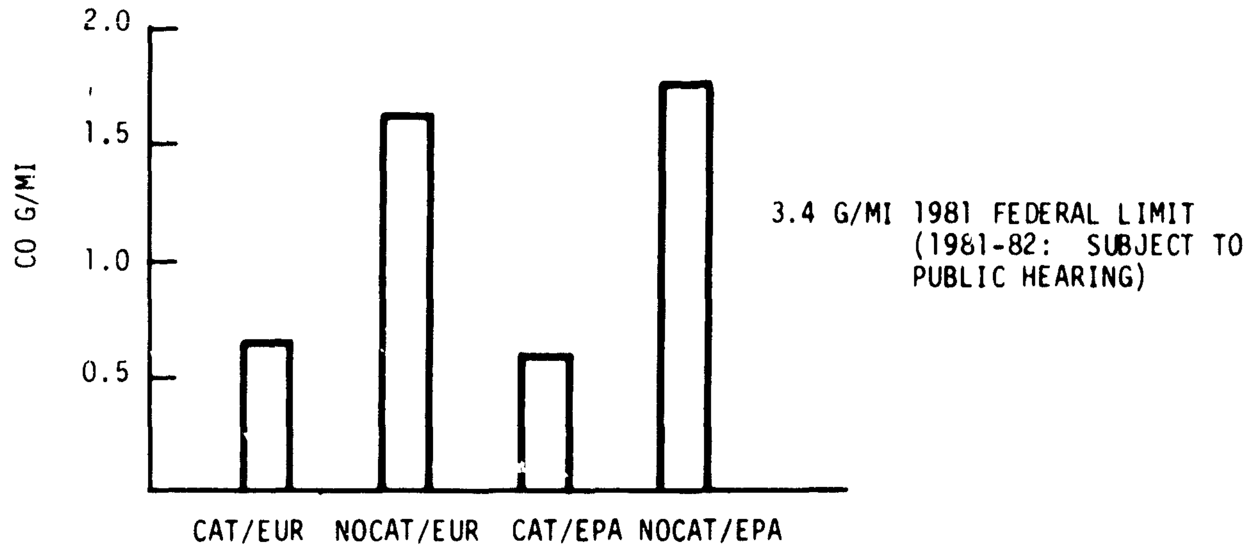


FIGURE 10. AUTOMOTIVE RESEARCH LABORATORY EMISSIONS OF A FIAT 131 NA DIESEL, FEDERAL TEST PROCEDURE

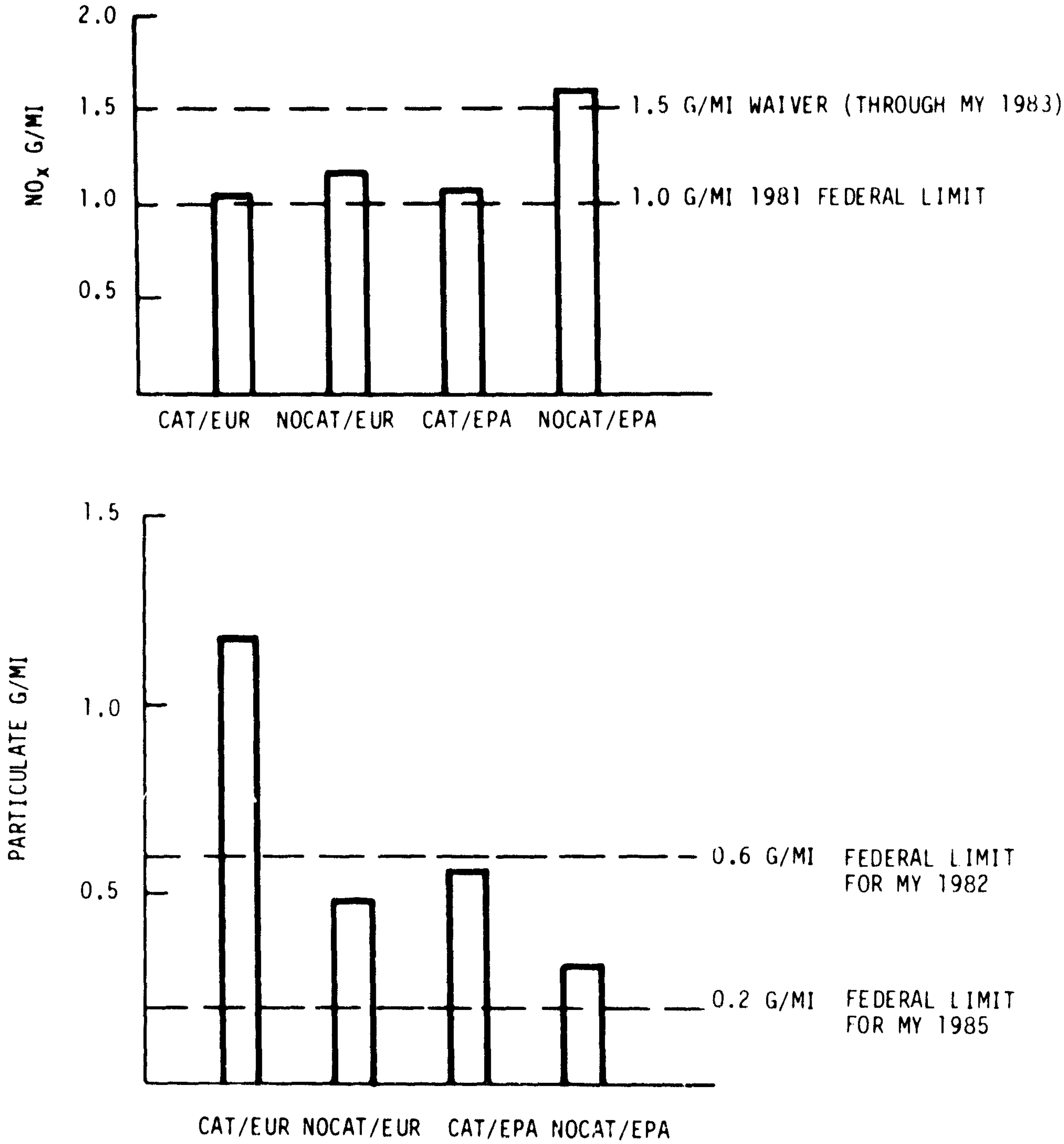


FIGURE 10. AUTOMOTIVE RESEARCH LABORATORY EMISSIONS OF A FIAT 131 NA DIESEL FEDERAL,TEST PROCEDURE (CONTINUED)

The prototype Fiat met the 1982 particulate emission standard of 0.6 g/mi in three of the four configurations, but did not meet the limit in the catalyst/European fuel configuration. Its inability to meet the standard in this case was due to the interaction of the catalyst and the fuel sulfur; this is discussed in greater detail in Section 4.3.

4.2 OVERALL RESULTS

Numerical tables of the results are included in the appendix. Figures 11-18 are bar graphs of emissions and fuel economy for each test configuration and cycle. Emissions and fuel economy values are heavily dependent on the test cycle, thus it is useful to refer to the drive cycle characteristics given in Table 7. For example, the average speed of the New York City Cycle is 6.6 mph; fuel economy values generally ranged between 10 and 16 mpg and emission rates were quite high, averaging, over all four configurations (cold and hot starts), 1.22/3.84/2.39/0.69, for HC/CO/NO_x/ particulate, g/mi respectively. On the other end of the spectrum is the FET highway cycle with an average speed of 48.2 mph. The Fiat 131 tested over the highway cycle generally exhibited the highest fuel economy and lowest emissions. For one configuration fuel economy values reached 38 mpg. The use of fifth gear improved fuel economy about 10%.

Since emission rates and fuel economy are temperature dependent, the cold start drive cycles produced noteworthy results. A comparison of FTP bag 1, cold start-transient cycle, to bag 3, hot start-transient cycle, indicates that vehicle warm-up produces a nominal 15% increase in fuel economy. Hydrocarbon, carbon monoxide, and particulate emissions decrease significantly, particularly in the catalyst-equipped vehicle. Figure 19 shows that the catalyst lights-off approximately 170 seconds into the bag 1 portion of the drive cycle. Below is an overview of the test results. The effects of the catalyst and fuel characteristics are detailed in Sections 4.3 and 4.4.

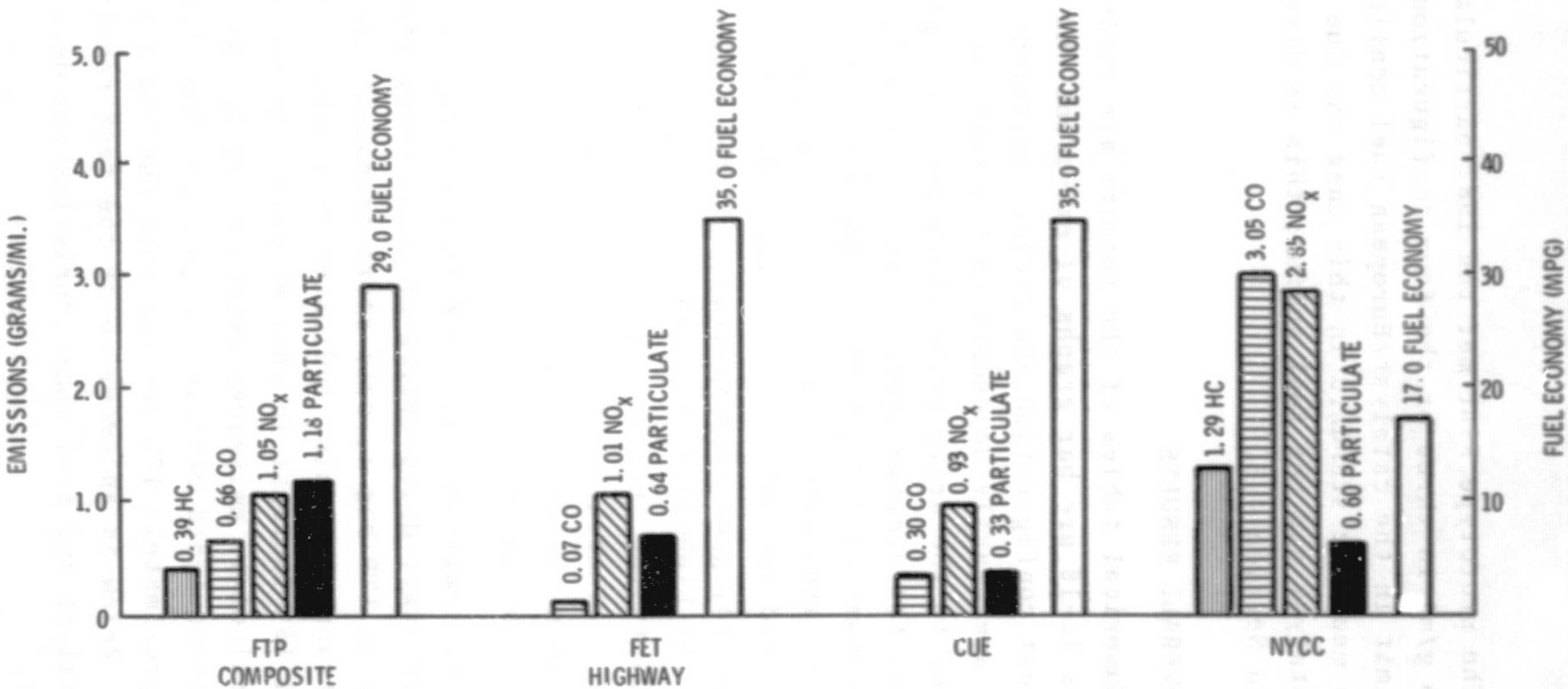


FIGURE 11. AUTOMOTIVE RESEARCH LABORATORY, EMISSIONS AND FUEL ECONOMY OF A FIAT 131 NA DIESEL: CATALYST/EUROPEAN FUEL, CYCLIC TESTS

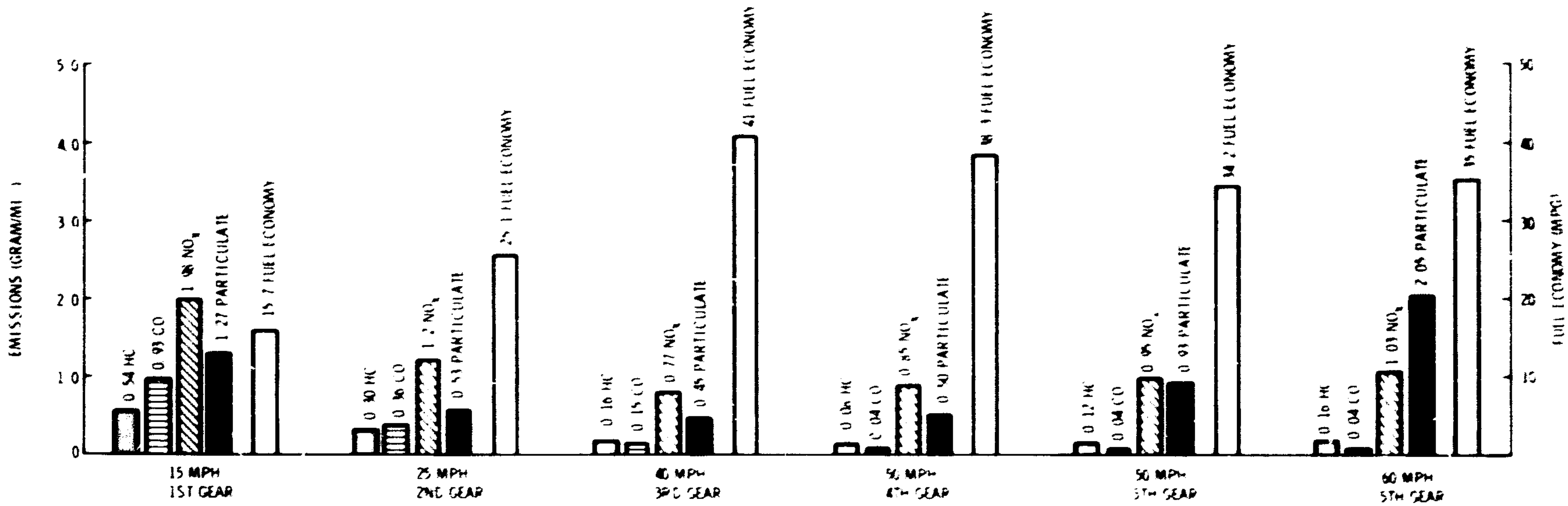


FIGURE 12. AUTOMOTIVE RESEARCH LABORATORY, EMISSIONS AND FUEL ECONOMY OF A FIAT 131 NA DIESEL: CATALYST/EUROPEAN FUEL, STEADY STATES

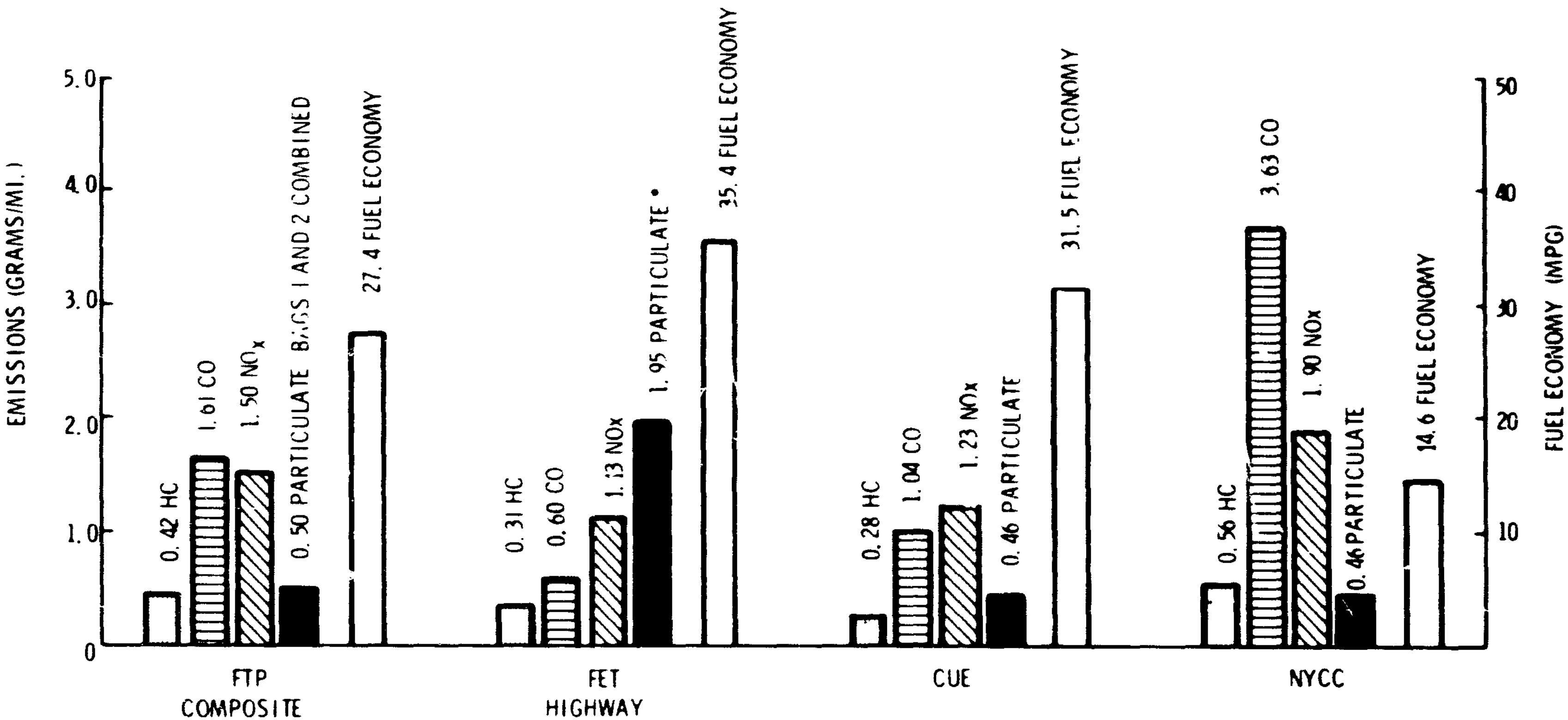


FIGURE 13. AUTOMOTIVE RESEARCH LABORATORY, EMISSIONS AND FUEL ECONOMY OF A FIAT 131 NA DIESEL: NO CATALYST/EUROPEAN FUEL, CYCLIC TESTS

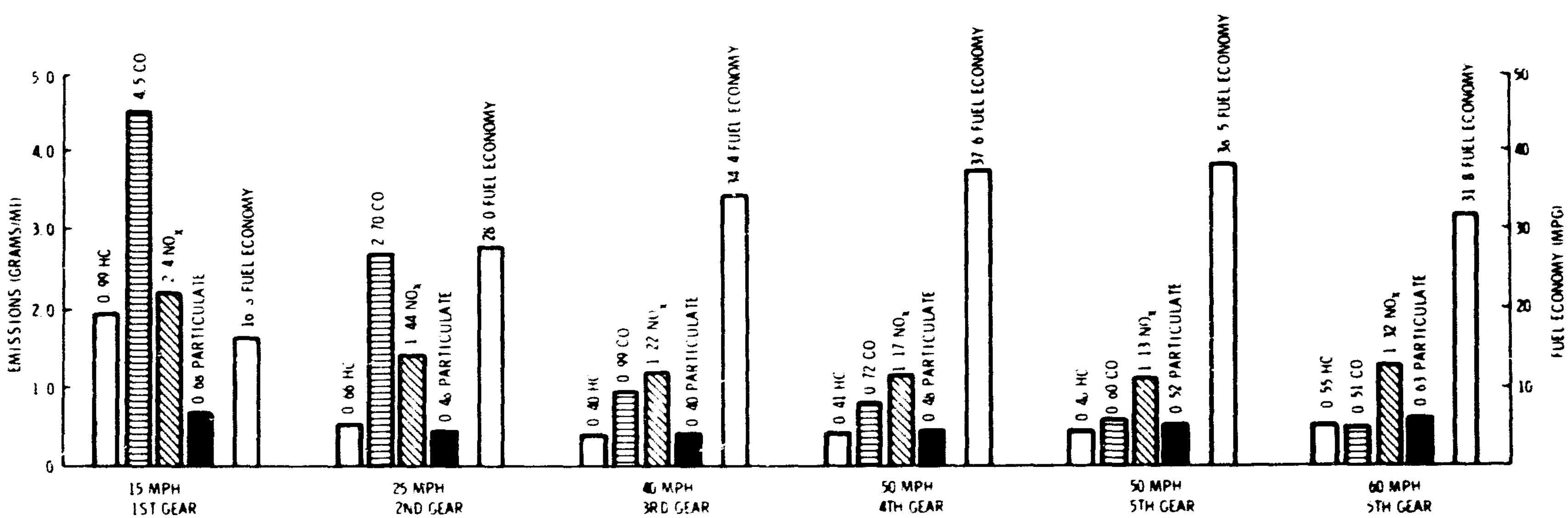


FIGURE 14. AUTOMOTIVE RESEARCH LABORATORY, EMISSIONS AND FUEL ECONOMY OF A FIAT 131 NA DIESEL: NO CATALYST/EUROPEAN FUEL, STEADY STATES

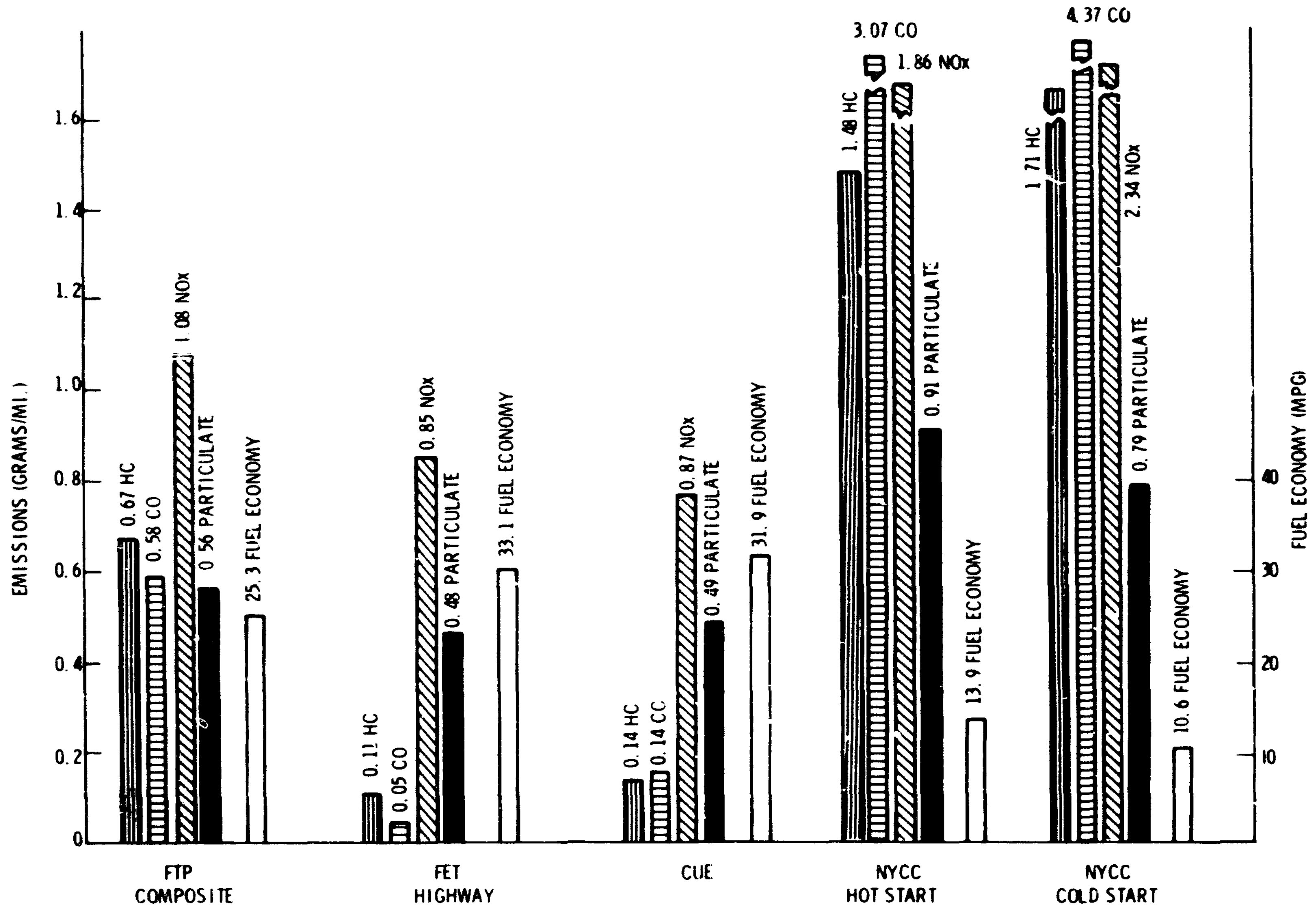


FIGURE 15. AUTOMOTIVE RESEARCH LABORATORY, EMISSIONS AND FUEL ECONOMY OF A FIAT 131 NA DIESEL: CATALYST/EPA FUEL, CYCLIC TESTS

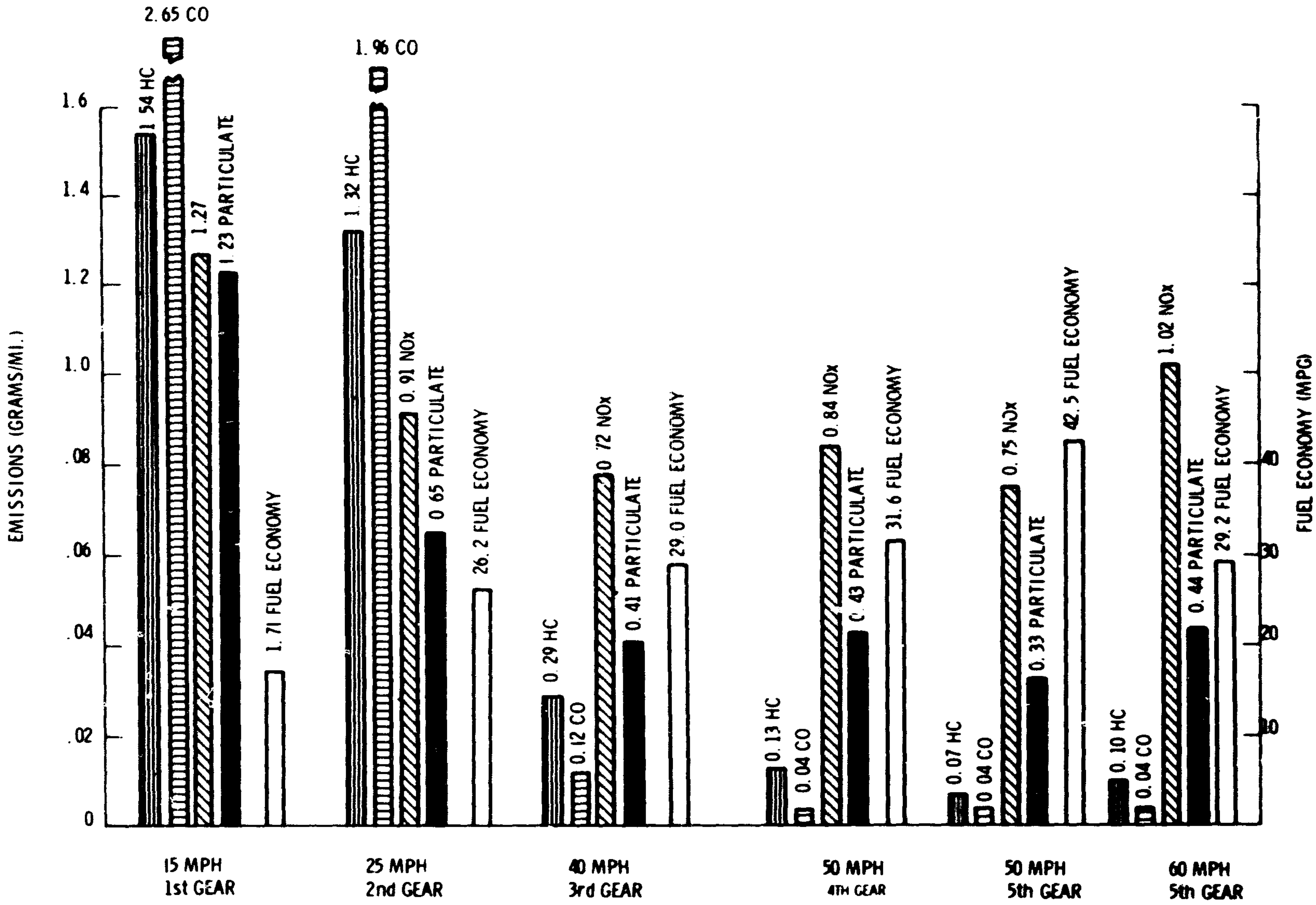


FIGURE 16. AUTOMOTIVE RESEARCH LABORATORY, EMISSIONS AND FUEL ECONOMY OF A FIAT 131 NA DIESEL: CATALYST/EPA FUEL, STEADY STATES

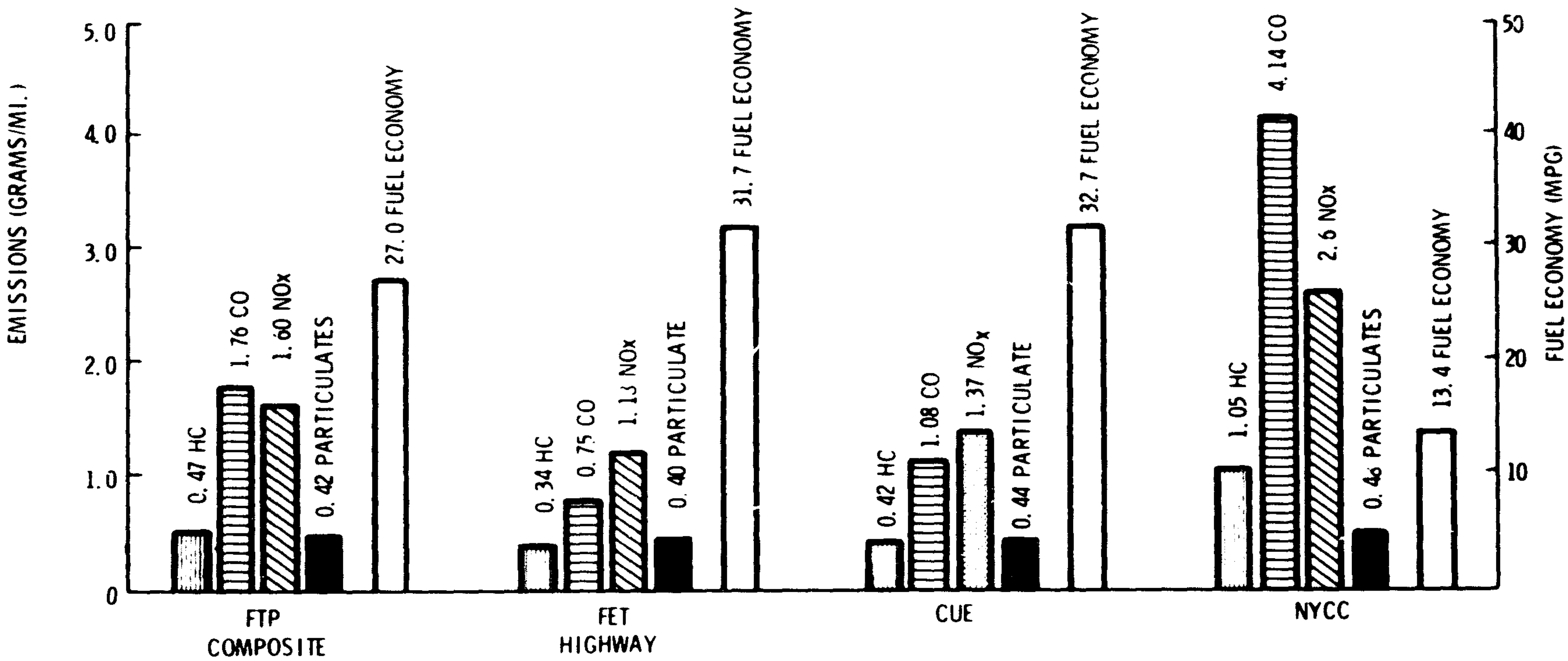


FIGURE 17. AUTOMOTIVE RESEARCH LABORATORY, EMISSIONS AND FUEL ECONOMY OF A FIAT 131 NA DIESEL: NO CATALYST/EPA FUEL, CYCLIC TESTS

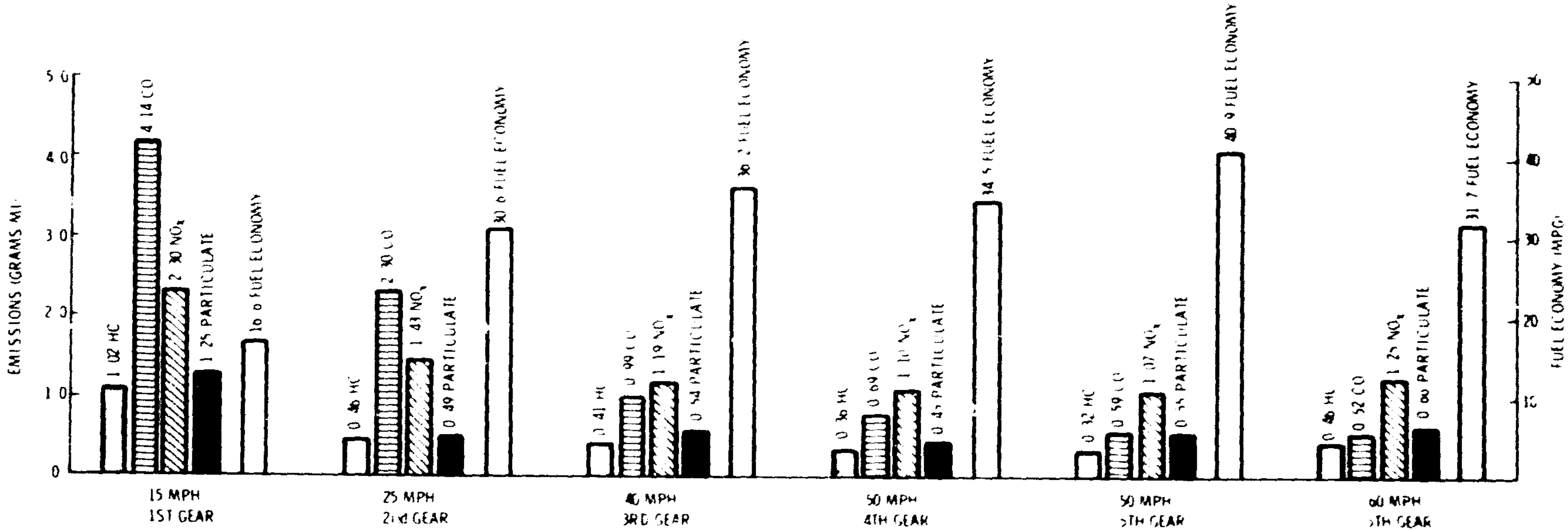


FIGURE 18. AUTOMOTIVE RESEARCH LABORATORY, EMISSIONS AND FUEL ECONOMY OF A FIAT 131 NA DIESEL: NO CATALYST/EPA FUEL, STEADY STATES

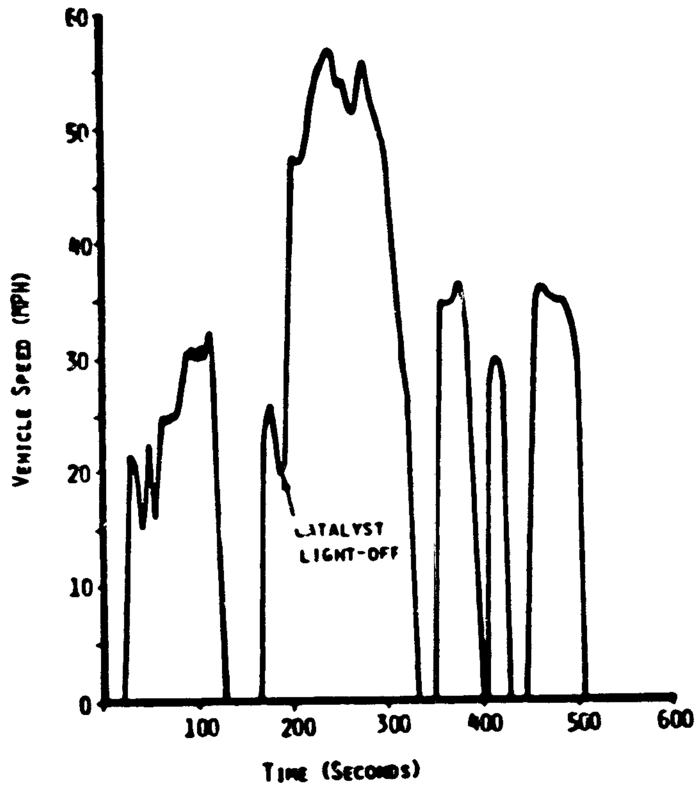


FIGURE 19. FEDERAL TEST PROCEDURE URBAN DRIVE SCHEDULE (0 TO 505 SECONDS)

4.2.1 Hydrocabrons

4.2.1.1 Federal Test Procedures - As is seen in Figure 20, FTP composite hydrocarbon levels ranged from 0.39 to 0.67 g/mi, depending on the configuration. The highest hydrocarbon levels in the FTP test set were produced by the catalyst-equipped vehicle run on EPA fuel. This was probably due to the fact that engine optimization relative to fuel was based on European fuel characteristics. No attempt was made to change this optimization to compensate for the different EPA fuel characteristics.

HC measurements for the cat./Eur, no cat./Eur, and no cat/EPA configurations were not significantly different.

4.2.1.2 Steady State Tests - Hydrocarbon levels were highest for all configurations at low speeds as is indicated in Figure 21. At low speeds and low loads, combustion is relatively inefficient because of lower combustion chamber and gas temperatures. Lowest hydrocarbon levels were produced at the 50-mph test point. A slight increase in HC levels was observed at the 60-mph test point, presumably due to increased fuel-air ratios, oxidation limitation due to lower local oxygen concentrations, and decreased reaction times. The catalyst (when activated) was generally quite effective in reducing HC levels.

4.2.2 Carbon Monoxide

4.2.2.1 Federal Test Procedure - FTP composite carbon monoxide levels ranged from 0.58 to 1.76 g/mi (Figure 20). The catalyst was effective in reducing CO levels; carbon monoxide reduction, in fact, averaged approximately 95% in the FTP cycle.

4.2.2.2 Steady State Tests - CO levels, like hydrocarbon emissions, were highest at low speeds, independent of the configuration. The major factor producing this trend is basically the same as that

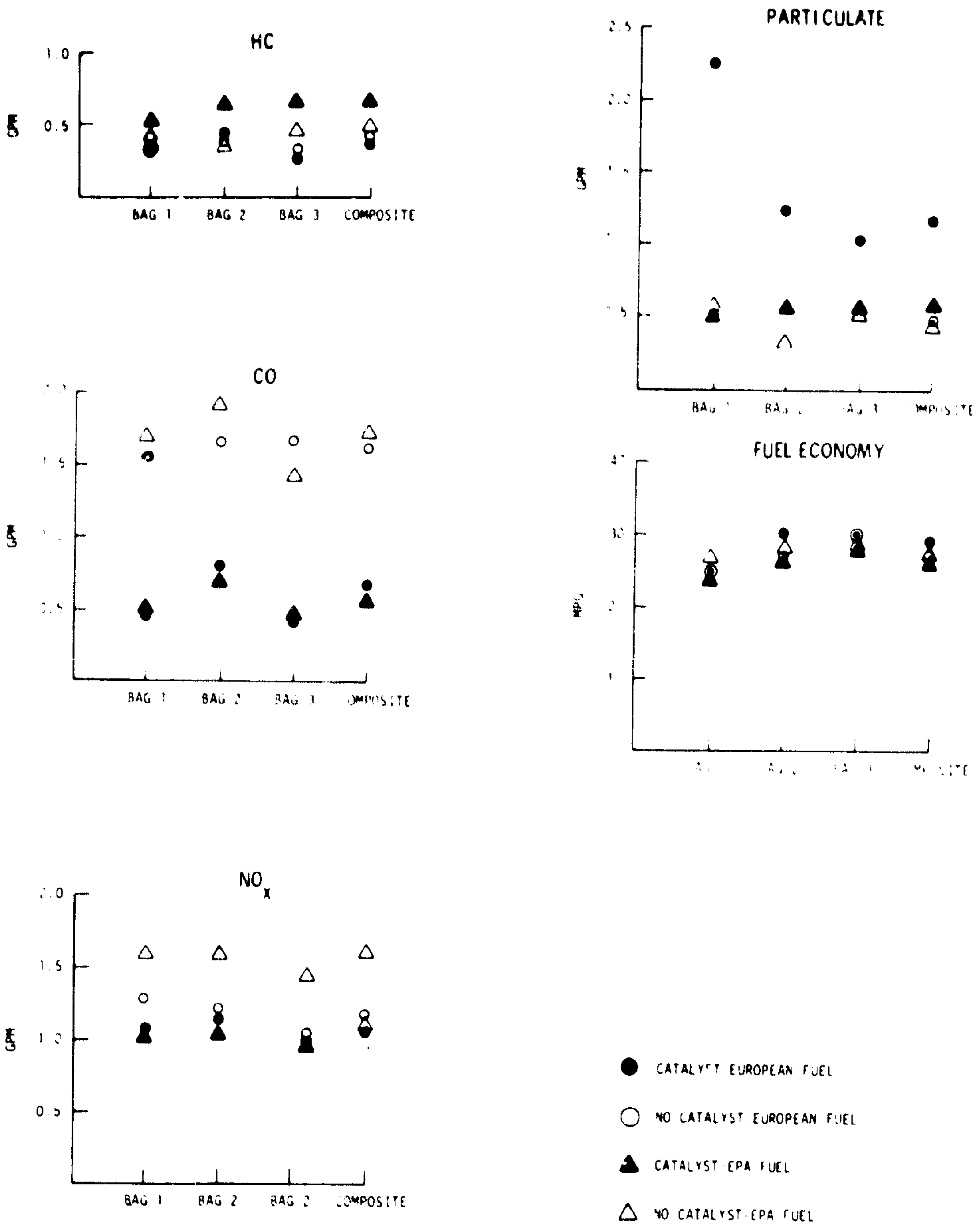


FIGURE 20. AUTOMOTIVE RESEARCH LABORATORY, EMISSIONS AND FUEL ECONOMY OF FIAT 131 NA DIESEL, FEDERAL TEST PROCEDURE

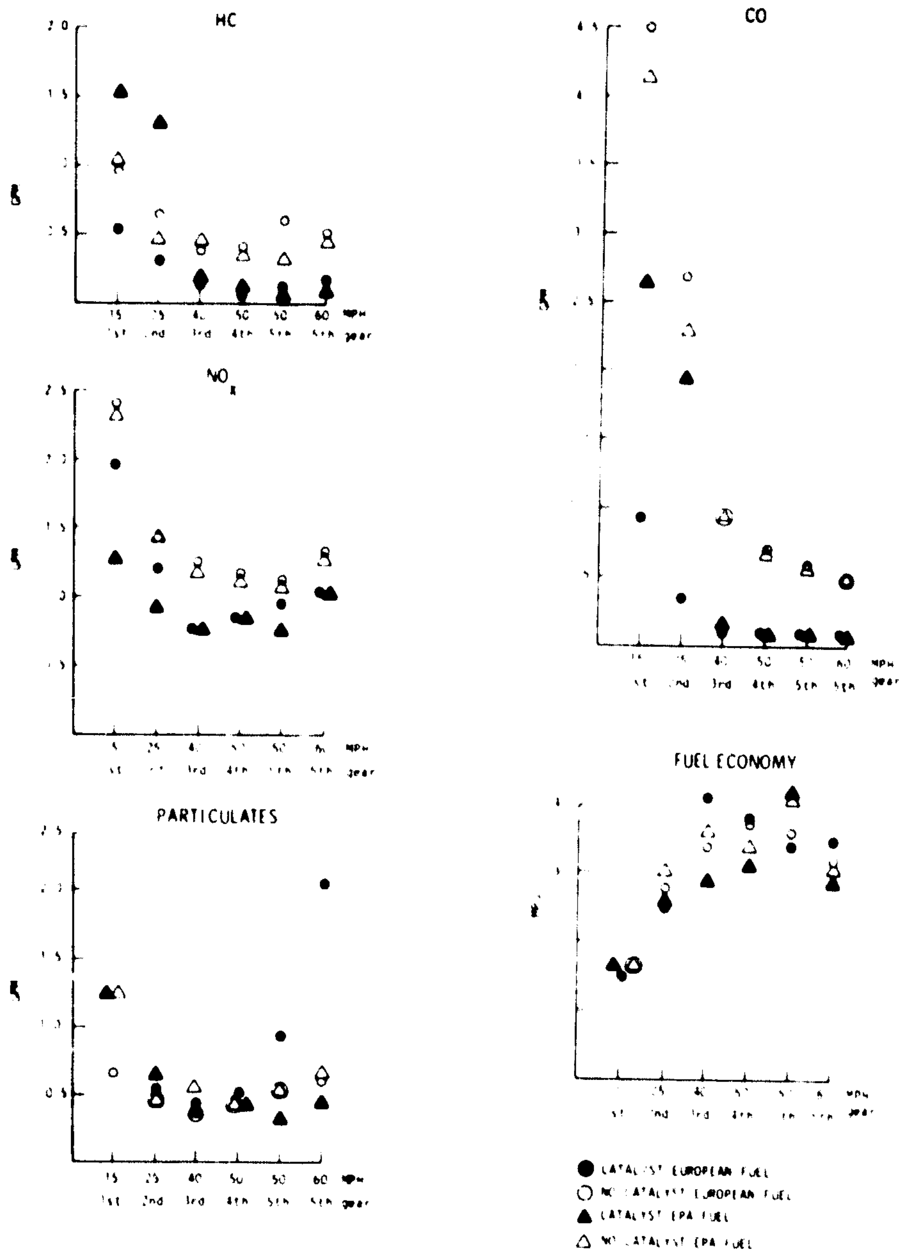


FIGURE 21. AUTOMOTIVE RESEARCH LABORATORY, EMISSIONS AND FUEL ECONOMY OF A FIAT 131 NA DIESEL, STEADY STATES

which was responsible for the hydrocarbon trends, i.e., the extent of oxidation. The oxidation process is mainly dependent on local gas temperatures, local oxygen concentration, mixing, and time available for oxidation.

4.2.3 Oxides of Nitrogen

4.2.3.1 Federal Test Procedure - Average FTP nitrogen oxide levels ranged from 1.05 g/mi to 1.60. The highest levels were produced while the vehicle was assembled in the no cat/EPA fuel/(no injection timing retard) configuration. Again, specific fuel optimization (or lack of it) was probably a major factor in the production of such a trend.

4.2.3.2 Steady-State Tests - Nitrogen oxide formation is temperature dependent, as well as dependent on the amount of fuel injected. The decreases in NO_x levels with increasing speed (and thus increasing fuel-to-air ratios) were expected. (Figure 21). Further discussion of these trends is included in the catalyst discussion (Section 4.3).

4.2.4 Particulates

4.2.4.1 Federal Test Procedure

Average particulate emissions ranged from 0.42 to 1.18 g/mi. for the FTP cycle (Figure 20). Except for the cat/Eur configuration, average configuration-to-configuration values varied little, i.e., from 0.42 to 0.56 g/mi. The high average level produced by the cat/Eur configured vehicle, 1.18 g/mi, is due primarily to the interaction of the catalytic surface and the fuel sulfur.

4.2.4.2 Steady States

As was to be expected, particulate levels were lowest at mid-speeds (40 and 50 mph) at which combustion processes are the most complete (Figure 21).

4.3 EFFECT OF THE CATALYST

The catalyst was generally effective in reducing hydrocarbon and carbon monoxide levels, as expected. Figures 22 through 29 are graphical representations of the percent changes in emission rates and fuel economy levels that occurred when the catalyst was removed and, simultaneously, the static injection timing (SIT) was adjusted, that is, effectively advanced, to the manufacturer's prescribed SIT. Figure 23 illustrates the percent variations which occurred as a result of the change in configuration from catalyst/ European fuel to no catalyst/European fuel. Hydrocarbon and carbon monoxide levels dramatically increased when the catalyst was removed; (minimum nominal increases were about 20%). Nitrogen oxides also showed a consistent increase, presumably due to the advanced SIT. Particulate levels decreased, a consequence of the removal of the catalytic surface with which the particulates interact to produce sulfates ($SO_2 \rightarrow SO_4^=$). Figures 22, 24, and 25 exhibit less consistent results; generally, however, there is agreement with the above-stated trends. As was expected, the greatest variability was exhibited by the hydrocarbon emission rates.

The effect of retarded injection timing is evident in certain hydrocarbon and carbon monoxide percent variations. During low-speed tests, the catalyst does not heat up sufficiently to "light-off," i.e., become active. Consequently, the effect of retarded timing predominates and tends to increase HC and CO levels. Retarded timing shortens ignition delay and results in lower peak combustion temperatures; oxidation of HC and CO is thus less likely to occur.

Conversely, decreases in HC and CO levels should be produced by the removal of the catalyst and the advancement of the S.I.T. when the catalyst is inactive. The HC trend is evident in low-speed, steady-state tests (Figure 23, at 15 and 25 mph) and in the NYCC (Figures 22 and 24) which has an average speed of 6.6 mph.

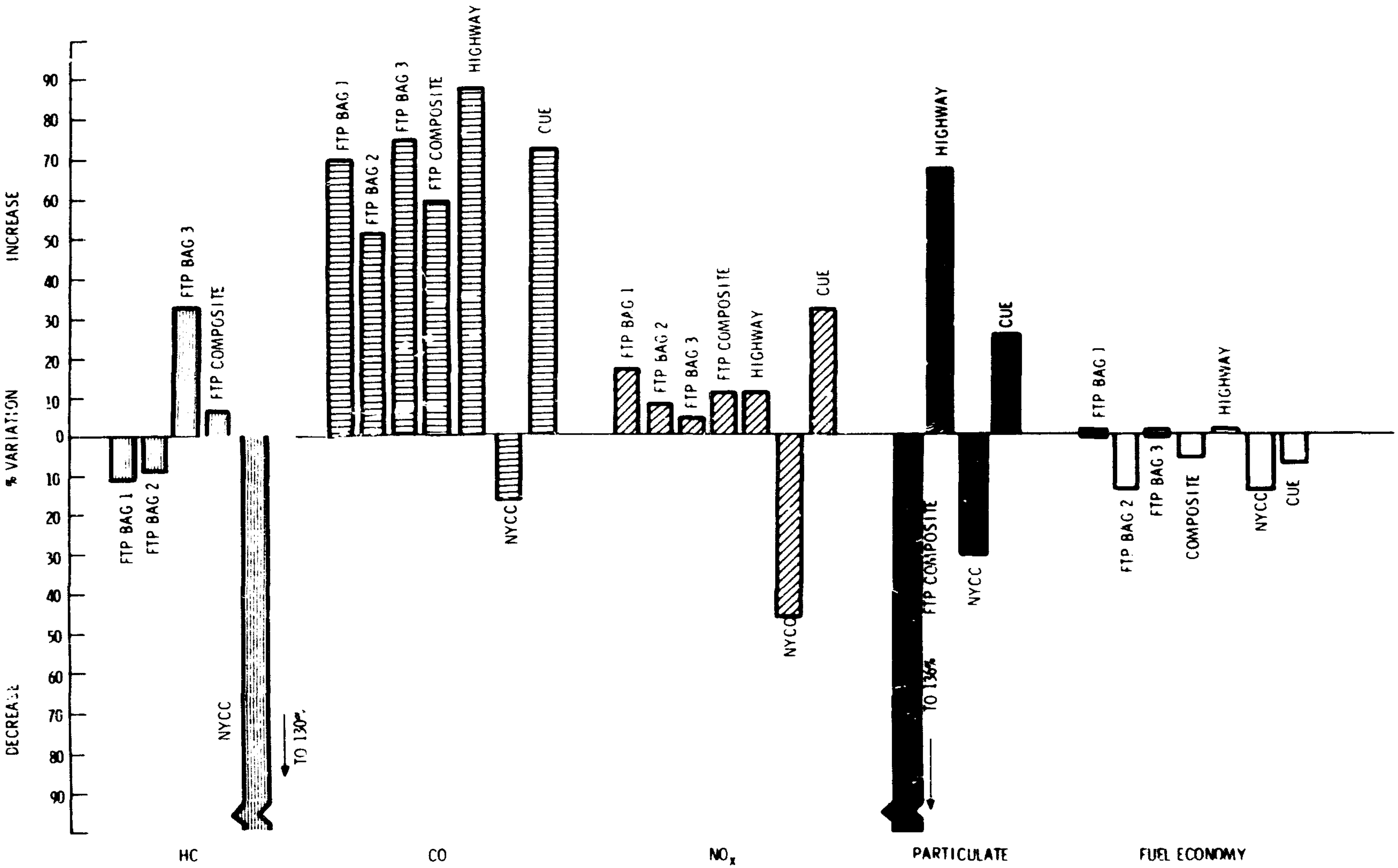


FIGURE 22. AUTOMOTIVE RESEARCH LABORATORY, FIAT 131 NA, CHANGE IN TEST CONFIGURATION: CATALYST/EUROPEAN FUEL TO NO CATALYST/EUROPEAN FUEL, CYCLIC TESTS

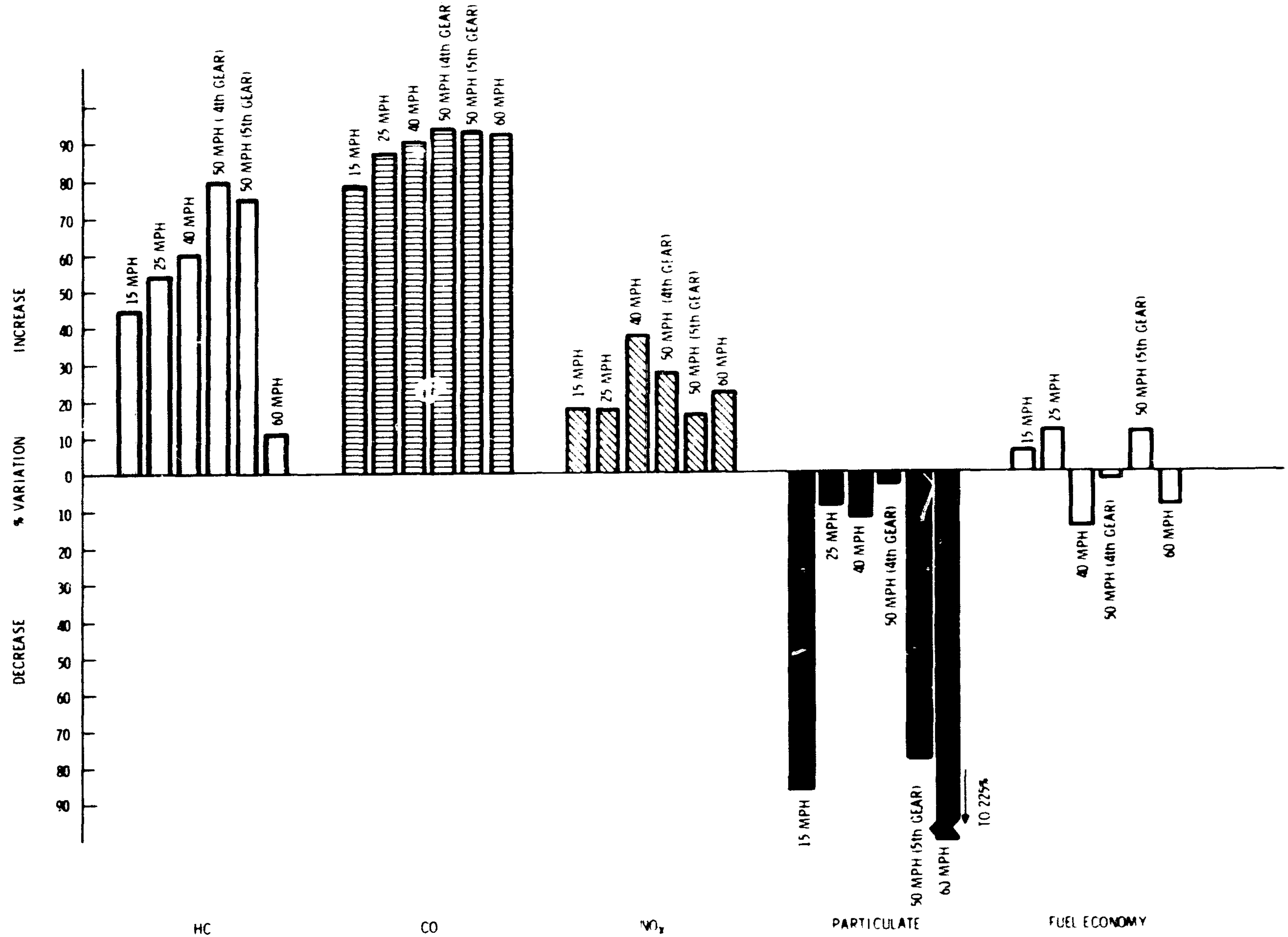


FIGURE 23. AUTOMOTIVE RESEARCH LABORATORY, FIAT 131 NA, CHANGE IN TEST CONFIGURATION: CATALYST/EUROPEAN FUEL TO NO CATALYST/EUROPEAN FUEL, STEADY STATES

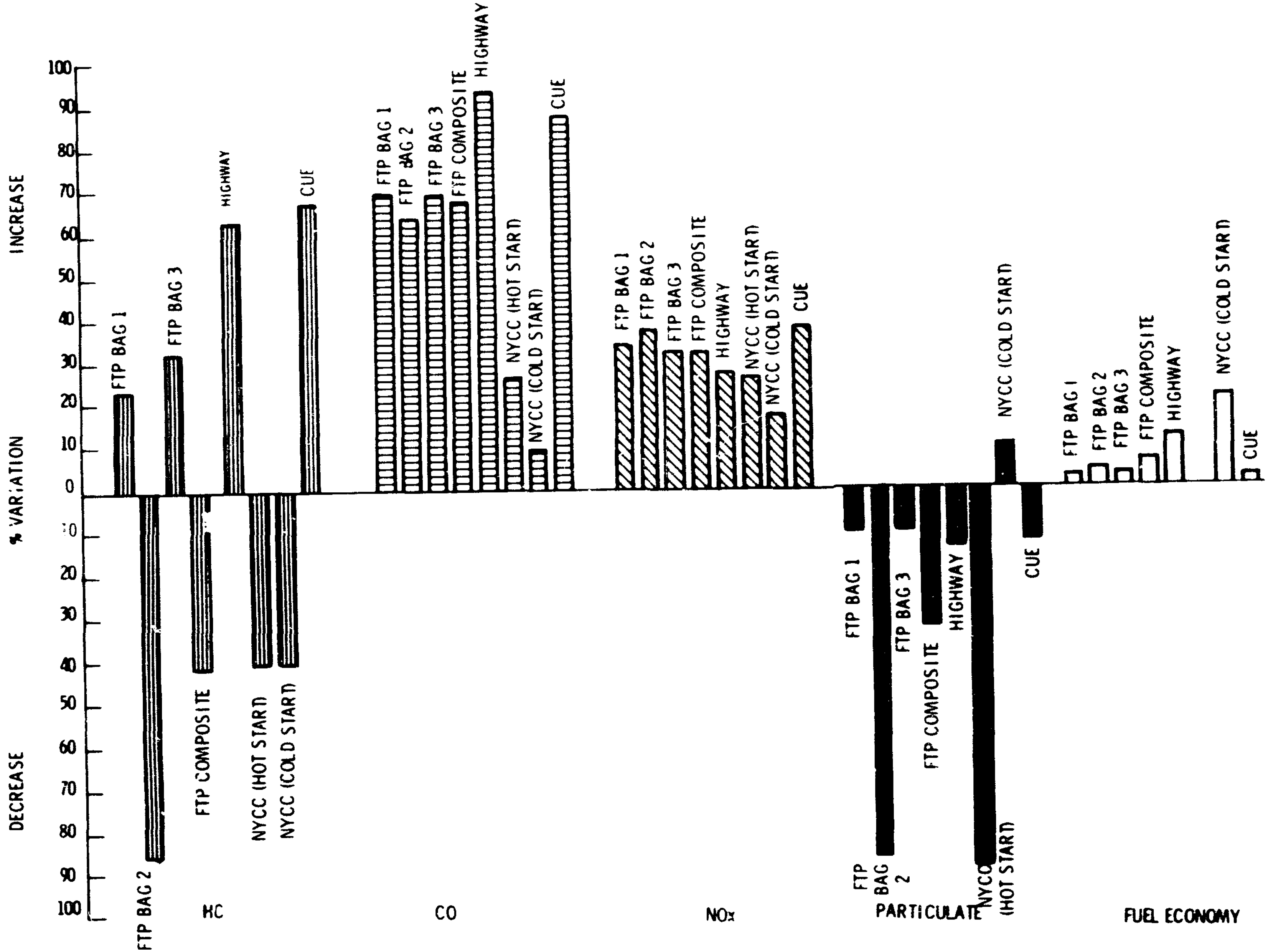


FIGURE 24. AUTOMOTIVE RESEARCH LABORATORY, FIAT 131 NA, CHANGE IN TEST CONFIGURATION: CATALYST/EPA FUEL TO NO CATALYST/EPA FUEL, CYCLIC TESTS

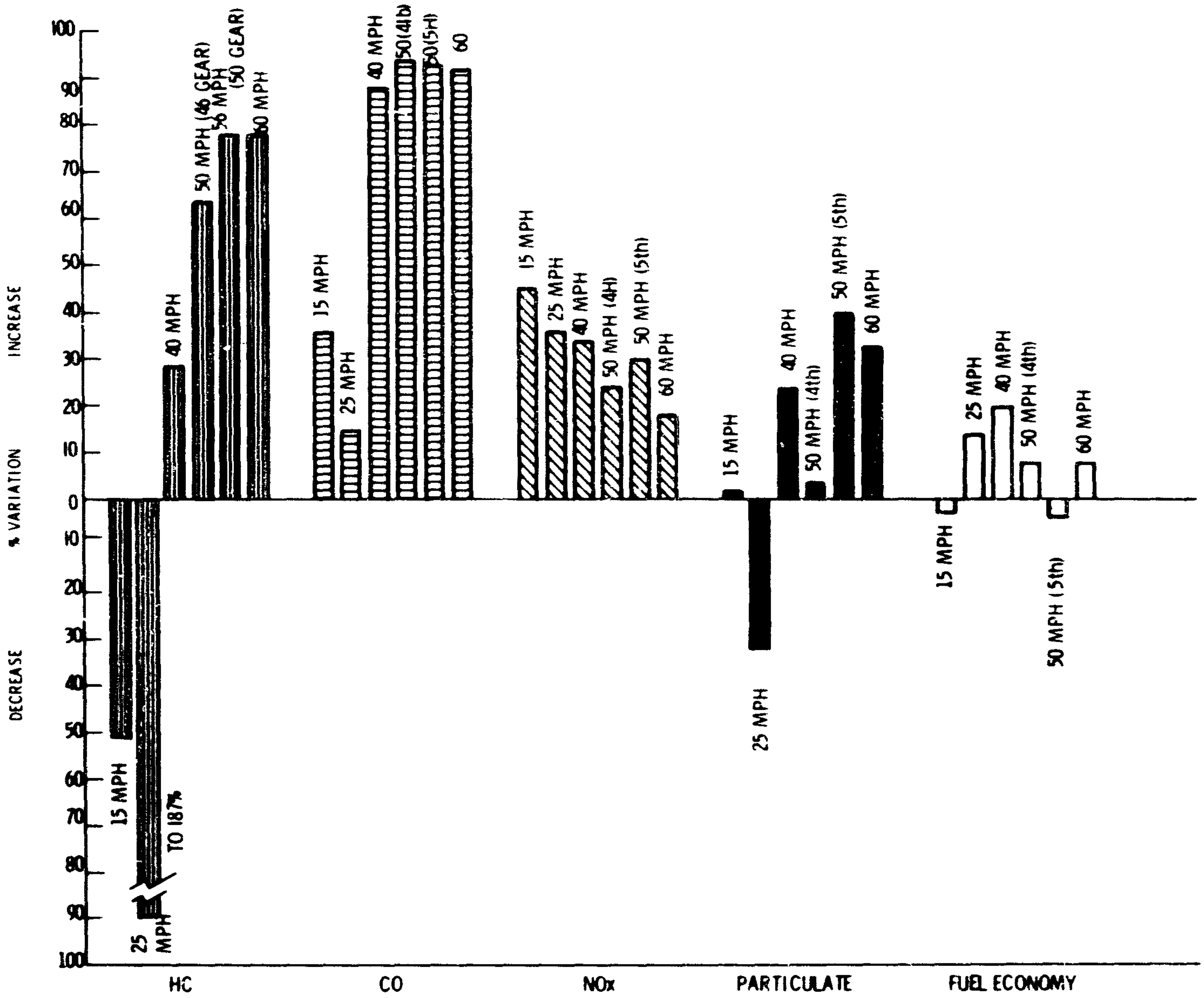


FIGURE 25. AUTOMOTIVE RESEARCH LABORATORY, FIAT 131 NA, CHANGE IN TEST CONFIGURATION: CATALYST/EPA FUEL TO NO CATALYST/EPA FUEL, STEADY STATES

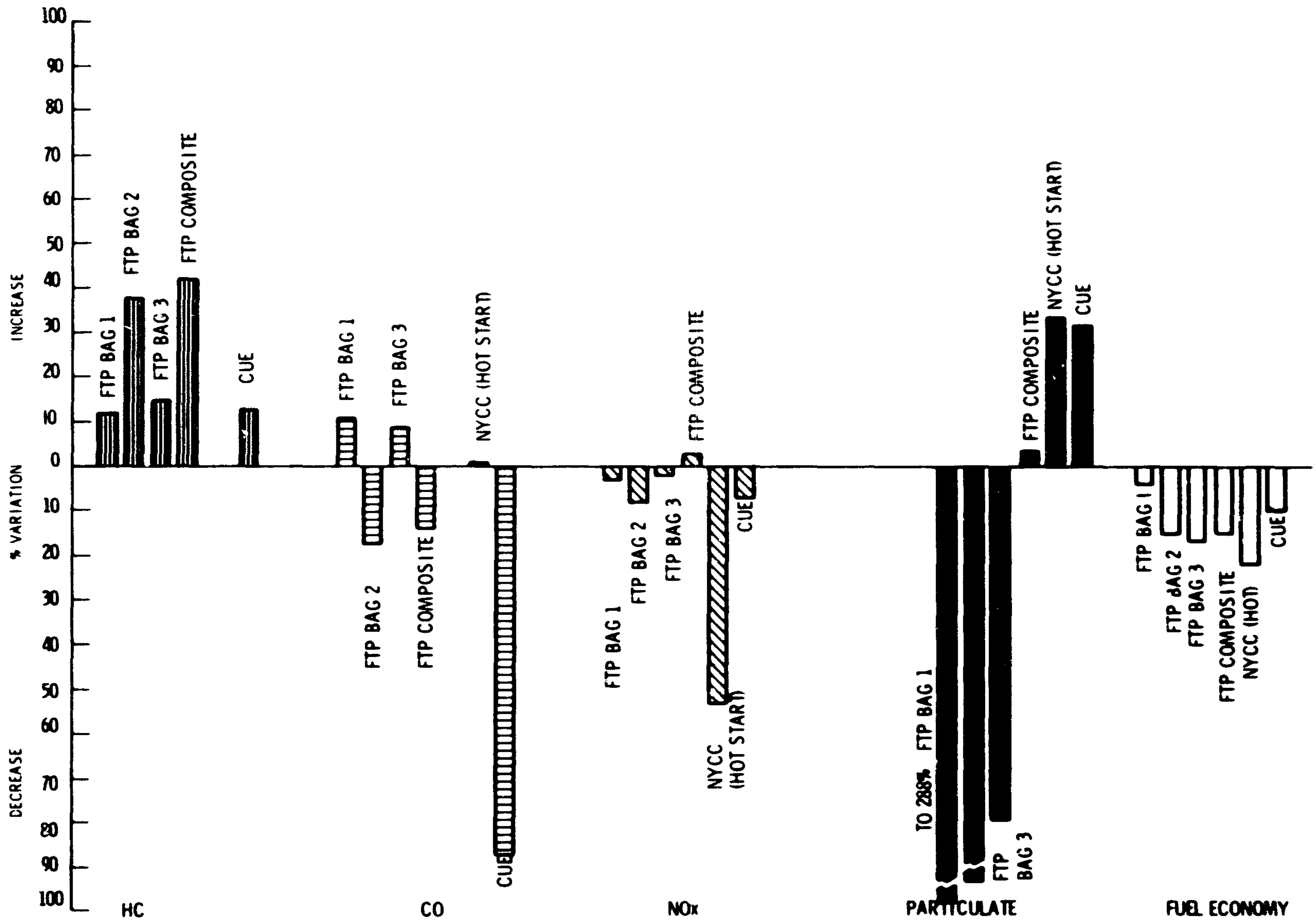


FIGURE 26. AUTOMOTIVE RESEARCH LABORATORY, FIAT 131 NA, CHANGE IN TEST CONFIGURATION: CATALYST/EUROPEAN FUEL TO CATALYST/EPA FUEL, CYCLIC TESTS

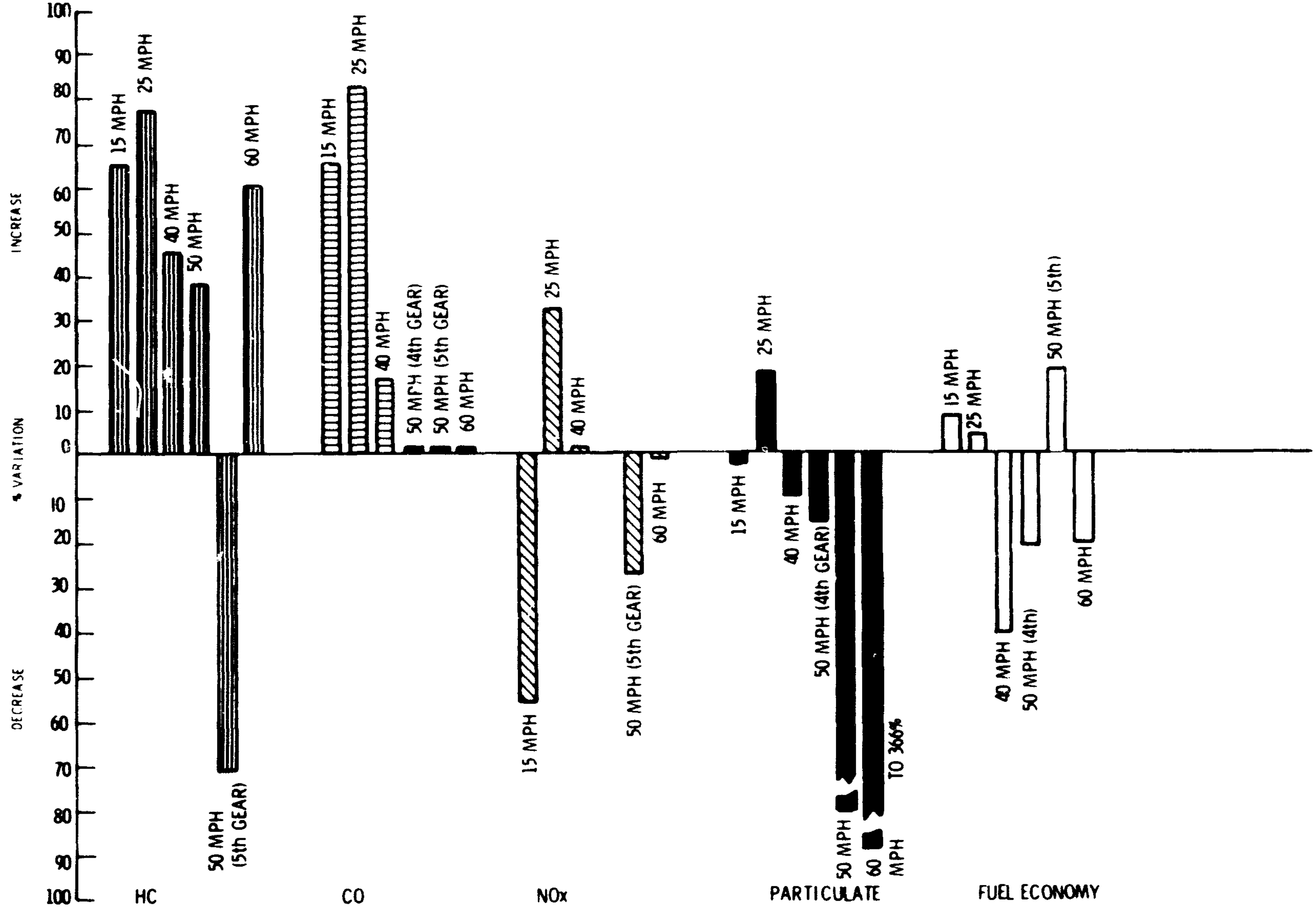


FIGURE 27. AUTOMOTIVE RESEARCH LABORATORY, FIAT 131 NA, CHANGE IN TEST CONFIGURATION: CATALYST/EUROPEAN FUEL TO CATALYST/EPA FUEL, STEADY STATES

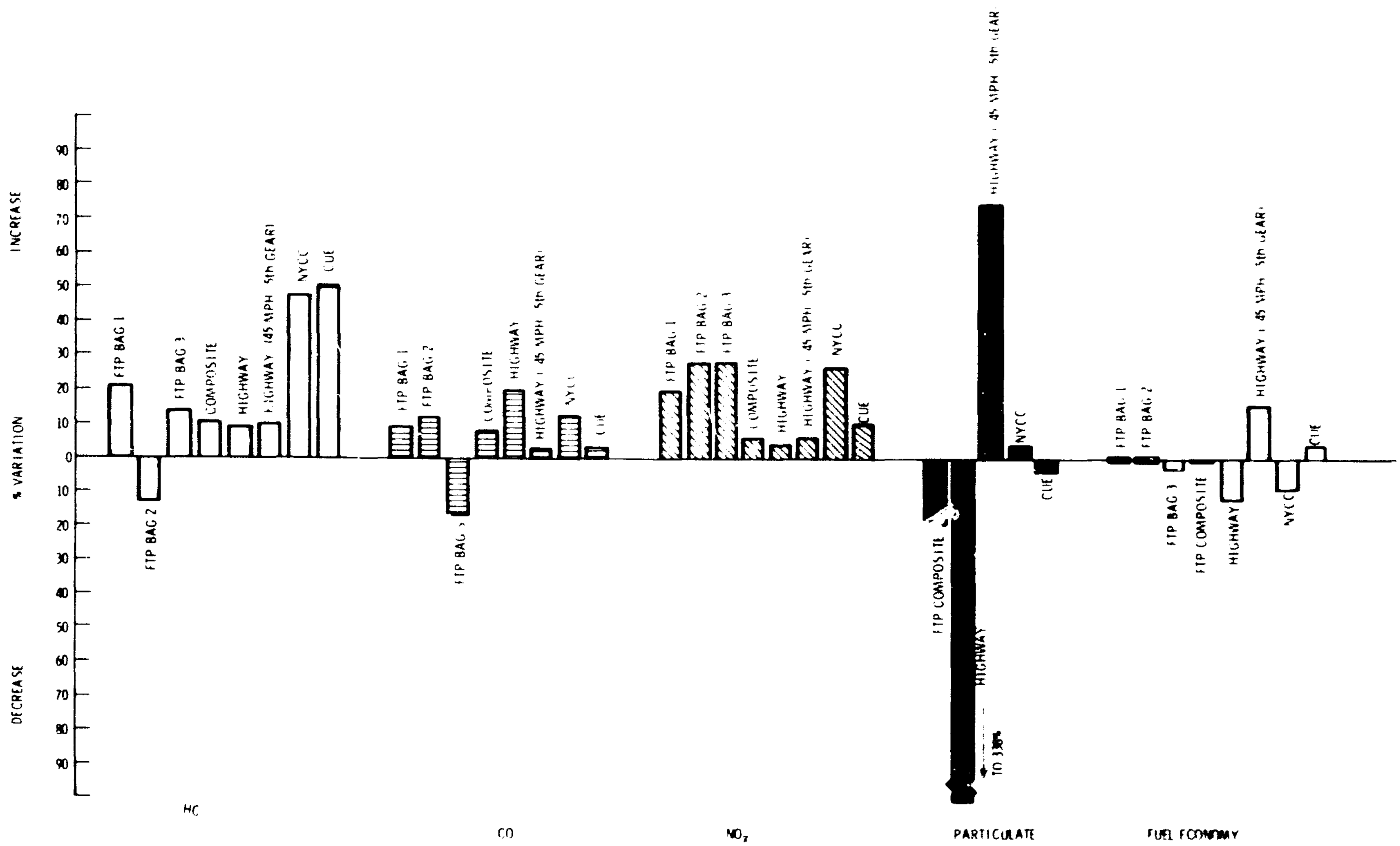


FIGURE 28. AUTOMOTIVE RESEARCH LABORATORY, FIAT 131 NA, CHANGE IN TEST CONFIGURATION: NO CATALYST/EUROPEAN FUEL TO NO CATALYST/EPA FUEL, CYCLIC TESTS

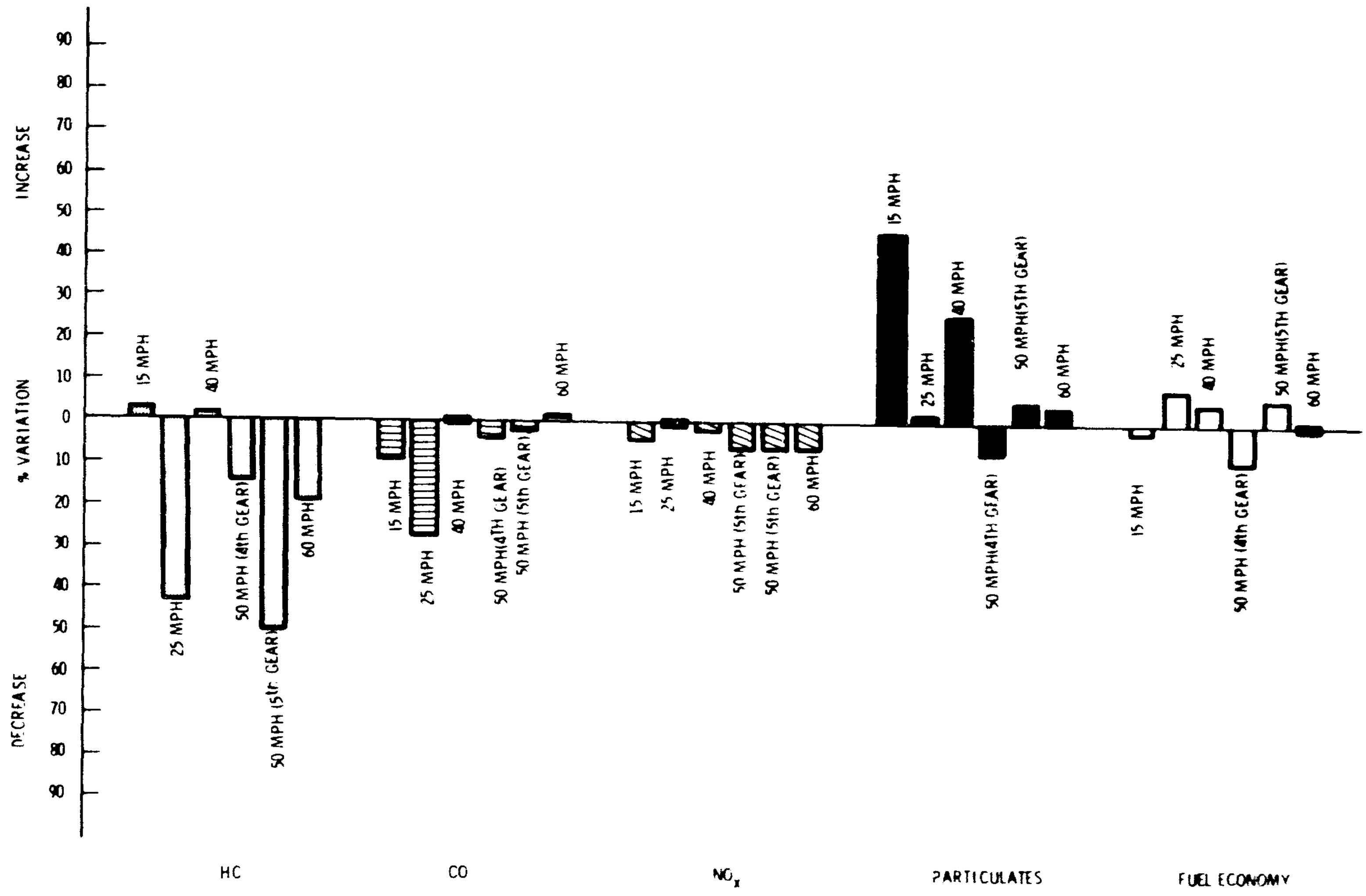


FIGURE 29. AUTOMOTIVE RESEARCH LABORATORY, FIAT 131 NA, CHANGE IN TEST CONFIGURATION: NO CATALYST/EUROPEAN FUEL TO NO CATALYST/EPA FUEL, STEADY STATES

Contradictory trends, such as those exhibited in the hydrocarbon levels in Figure 24, have not been explained.* Such inconsistencies are presumably due to test-to-test variability, e.g, catalyst and/or exhaust temperature variations.

Finally, the presence or absence of the catalyst and the simultaneous injection timing alterations had no significant effect on fuel economy levels.

4.4 FUEL EFFECTS

As is obvious from a brief examination of Figures 26 through 29, the percent variation of emissions due to fuel change (European to EPA fuel) is sporadic. Data trends are difficult to determine and are generally insufficient as the sole basis from which to draw definitive conclusions. Furthermore, because fuel properties are interrelated, the fuel properties that are responsible for emission rate increases or decreases can not be determined without a statistically designed text matrix. This data set, however, does generally confirm the work of previous fuel effect studies. The following outlines these trends.

Previous investigations have determined that hydrocarbon emissions are related mainly to four fuel characteristics: specific gravity, viscosity, 90% boiling point, and cetane number. In an analysis of forty-six fuels conducted by Burley and Rosebrock (SAE 790923),[5] low values of these characteristics were accompanied by higher hydrocarbon emissions. The EPA fuel used in the TSC study had specific gravity, lower cetane values and higher 90% boiling point, and, in general, hydrocarbon levels were higher when the Fiat was run on EPA fuel. (A viscosity determination was not included in the fuel analysis.)

*HC levels also showed the greatest run-to-run variability of all measured emissions within a given test configuration. This variability is consistent with that found by other investigators.

Broering and Holt (SAE 740692)[6] also found higher HC emissions with lower cetane fuels. Figures 26, 27, and 28 illustrate this trend. Tuteja and Clark (SAE 800331) found no direct correlation of HC levels to cetane numbers, but did find a correlation with the 50% distillation point. Again, in regard to the 50% distillation point, this investigation produced supportive results. The EPA fuel had a lower 50% distillation point and the EPA fuel generally produced lower HC levels.

Carbon monoxide, nitrogen oxides, and particulate levels were sporadic. Trends do not appear with any significant frequency. However there were a few notable exceptions. Without a more extensive test matrix, it is nearly impossible to illuminate the source(s) of these variations. Some data scatter can probably be attributed to the variations in the test-to-test variability (e.g., driver variability, variations in ambient conditions, etc.). Injection timing requirements vary from fuel-to-fuel but no attempt was made in this study to optimize injection timing or any engine parameters which might have been affected by fuel characteristics.

One well-defined trend in particulate emissions can be linked to the sulfur content of each fuel. The sulfur contents of the EPA and European fuels were, respectively, 0.25% and 0.77%. In a catalyst-equipped vehicle, the higher sulfur content results in higher particulate emissions where particulate sulfates are produced by the interaction of the fuel sulfur and the catalytic surfaces. Figures 26 and 27 show this dramatic decrease in particulates (catalyst/European fuel to catalyst/EPA fuel configuration) and the apparent decrease in sulfate production at high speeds and during the cold phase of the Federal Test Procedure.

Finally, fuel economy levels were not significantly affected by the use of the two different fuels.

5. CONCLUSIONS

Based on the data and results of the naturally aspirated Fiat 131 tested over a variety of cyclic and steady-state tests, the following conclusions can be drawn.

(1) The oxidation catalyst used in conjunction with retarded injection timing is effective in reducing regulated emissions in the diesel-powered vehicle without significant effects on fuel economy. Reductions in hydrocarbons and carbon monoxide emissions generally ranged from 20 to 70%; reductions in NO_x ranged from 10 to 40%. In regard to the implementation of catalysts on diesel-powered vehicles, a few additional points should be considered:

(i) Hydrocarbon and carbon monoxide levels are inherently lower in the diesel engine as compared with the gasoline-powered engine. Oxides of nitrogen are comparable, and in the diesel engine, particulates are much higher, (0 to 100 times higher on a total weight basis). Consequently, NO_x and particulates are of much greater concern.

(ii) Because the catalyst is simultaneously employed with injection timing retardation, which by itself produces increases in HC and CO, a cold engine/inactive catalyst actually produces more HC and CO than an engine operated without a catalyst and with retarded timing.

(iii) The presence of the catalyst increases particulate-sulfate emissions. This increase is directly dependent on the sulfur content of the fuel. This fact will become of increasing significance if broader-cut, low-grade fuels are employed. General opinion relative to future diesel fuels suggests that they will have increased levels of sulfur and aromatics and decreased volatility, trends which will exacerbate emissions problems.

(iv) The increased use of catalyst-equipped diesels without fuel desulfurization may have a deleterious effect on ambient air quality.

(v) Production line cost estimates for catalysts have ranged between $75 and a few hundred dollars. Replacement costs could be higher and assessments of catalyst durability are generally unavailable. Finally, most catalysts utilize scarce metals: platinum, palladium, and rhodium (for the three-way catalyst systems).

In summary, the oxidation catalyst as an emission control device does not currently appear to be a satisfactory method of HC and CO control for production-line diesel vehicles. For vehicles driven at low speeds (e.g., in congested areas) the catalyst used in conjunction with injection timing retardation actually increases hydrocarbon and carbon monoxide emission levels.

(2) To a large extent, this data base is insufficient as the sole basis from which to draw definitive conclusions about fuel and engine interactions. Because fuel properties are interrelated, the fuel characteristics that are responsible for emissions rate in-increases or decreases cannot be determined without a statistically designed test matrix. The following points , however, can be made.

(i) The particulate sulfate emission rate from a catalyst-equipped vehicle increases proportionally with the fuel sulfur content.

(ii) Engine optimization in regard to fuel type appears to have a significant impact on emissions.

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6. L.C. Broering and L.W. Holtman, "Effect of Diesel Fuel Properties on Emissions and Performance" SAE 740692.

7. A.D. Tuteja and D.W. Clark, "Comparative Performance and Emission Characteristics of Petroleum, Oil Shale, and Tar Sands Derived Diesel Fuels" SAE 800331.

TABLE A-1. TEST DATA SUMMARY, FIAT 131 NA DIESEL MEANS ($\bar{x}$) AND (WHERE APPROPRIATE) STANDARD DEVIATIONS (σ)

CYCLE	CONFIGURATION	EMISSIONS HC g/mi.	CO g/mi.	NO_x g/mi.	PARTICULATE g/mi.	FUEL ECONOMY MPG	COMMENTS
FTP Bag 1	Cat./Eur.	0.35	0.46	1.08	2.25	24.6	*Bags 1 & 2 combined
	No Cat./Eur.	0.41	1.55	1.29	-*	24.6	
	Cat./EPA	0.40	0.52	1.05	0.58	23.6	
	No Cat./EPA	0.52	1.71	1.59	0.52	24.4	
FTP Bag 2	Cat./Eur.	0.43	0.82	1.13	1.21	30.4	
	No Cat./Eur.	0.42	1.68	1.22	-*	27.4	*
	Cat./EPA	0.69	0.70	1.05	0.58	26.4	
	No Cat./EPA	0.37	1.92	1.67	0.31	27.5	
FTP Bag 3	Cat./Eur.	0.28	0.41	1.00	1.02	29.6	
	No Cat./Eur.	0.42	1.68	1.04	-*	29.5	*
	Cat./EPA	0.33	0.45	0.96	0.57	27.7	
	No Cat./EPA	0.49	1.44	1.44	0.52	28.6	
FTP Composite	Cat./Eur.	0.39	0.66	1.05	1.18	29.0	
	No Cat./Eur +	0.42	1.61	1.18	0.48	27.4	*Composite of above means
	Cat./EPA	0.67	1.58	1.08	0.56	25.3	
	No Cat./EPA	0.47	1.76	1.60	0.42	27.0	

TABLE A-1. TEST DATA SUMMARY, FIAT 131 NA DIESEL MEANS ($\bar{x}$) AND (WHERE APPROPRIATE) STANDARD DEVIATIONS (σ) (Continued)

CYCLE	CONFIGURATION		EMISSIONS HC g/mi.	CO g/mi.	NO_x g/mi.	PARTICULATE g/mi.	FUEL ECONOMY MPG	COMMENTS
HIGHWAY	Cat./Eur.	$\bar{x}$	-	0.07	1.01	0.64	35	
(no use of 5th gear)		σ	-	0.009	0.03	0.12	1.7	
	No Cat./Eur.	$\bar{x}$	0.31	0.60	1.13	0.40	33.0	
	No Cat./EPA	$\bar{x}$	0.34	0.75	1.18	0.40	31.7	
		σ	0.03	0.05	0.08	0.88	2.6	
HIGHWAY - Shift into 5th gear at 45 mph	No Cat./Eur.		0.27	0.72	1.09	0.35	35.7	
	Cat./EPA		0.11	0.05	0.85	0.48	33.1	
	No Cat./EPA		0.31	0.74	1.16	0.43+	37.8	+ave.of 2 runs
NYCC (hot)	Cat./Eur.		1.29	3.05	2.85	0.60*	17	
	No Cat./Eur.		0.56	3.63	1.90	0.46	14.6	
	Cat./EPA		1.48	3.07	1.86	0.91	13.9	
	No Cat./EPA		1.05	4.14	2.6	0.38	13.4	
(cold)	Cat./EPA		1.71	4.37	2.34	0.79*	10.6	
	No Cat./Epa		1.21	4.81	2.82	0.88	13.5	
CUE	Cat./Eur.		-	0.30	0.93	0.33	35	
	No Cat./Eur.		0.28	1.04	1.23	0.46	31.5	
	Cat./EPA		0.14	0.16	0.87	0.49	31.9	
	No Cat./EPA		0.42	1.08	1.37	0.44	32.7	

TABLE A-1. TEST DATA SUMMARY, FIAT 131 NA DIESEL MEANS ($\bar{x}$) AND (WHERE APPROPRIATE) STANDARD DEVIATIONS (σ) (Continued)

CYCLE	CONFIGURATION	EMISSIONS HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	COMMENTS
		g/mi.	g/mi.	g/mi.	g/mi.	MPG	
15 MPH/1st gear	Cat./Eur.	0.54	0.93	1.98	1.27	15.7	1 data pt.
	No Cat./Eur.	0.99	4.5	2.4	0.68	16.8	
	Cat./EPA	1.54	2.65	1.27	1.23	17.1	
	No Cat./EPA	1.02	4.14	2.30	1.25	16.6	
25 MPH/2nd gear	Cat./Eur	0.30	0.36	1.2	0.53	25.1	
	No Cat./Eur.	0.66	2.70	1.44	0.48	28.0	
	Cat./EPA	1.32	1.96	0.91	0.65	26.2	
	No Cat./EPA	0.46	2.30	1.43	0.49	30.6	
40 MPH/3rd gear	Cat./Eur.	0.16	0.10	0.77	0.45	41	
	No Cat./Eur.	0.40	0.99	1.22	0.40	34.3	
	Cat./EPA	0.29	0.12	0.78	0.41	29.0	
	No Cat./EPA	0.41	0.99	1.19	0.54	36.2	
50 MPH/4th gear	Cat./Eur.	0.08	0.04	0.85	0.50	38.3	
	No Cat./Eur.	0.41	0.72	1.17	0.48	38.6	
	Cat./EPA	0.13	0.04	0.84	0.43	31.6	
	No Cat./EPA	0.36	0.69	1.10	0.45	34.5	

TABLE A-1. TEST DATA SUMMARY, FIAT 131 NA DIESEL MEANS ($\bar{x}$) AND (WHERE APPROPRIATE) STANDARD DEVIATIONS (σ) (CONTINUED)

CYCLE	CONFIGURATION	EMISSIONS HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	COMMENTS
		g/mi	g/mi.	g/mi	g/mi	MPG	
30 MPH/5th gear	Cat./Eur.	0.12	0.04	0.95	0.93	34.2	
	No Cat/Eur	0.48	0.60	1.13	0.52	38.5	
	Cat./EPA	0.07	0.04	0.75	0.33	42.5	
	No Cat/EPA	0.32	0.59	1.07	0.55	40.9	
60 MPH/5th gear	Cat./Eur.	0.16	0.04	1.03	2.05	35	
	No Cat./Eur	0.55	0.51	1.32	0.63	31.8	
	Cat./EPA	0.10	0.04	1.02	0.44	29.2	
	No Cat/EPA	0.46	0.52	1.25	0.66	31.7	

TABLE A-1. TEST DATA, FIAT 131 DIESEL
CATALYST/EUROPEAN FUEL (Cont.)

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	g/mi	g/mi	MPG	Date/Comments
HIGHWAY	-	0.07	1.01	0.48	35	8/31
	-	0.05	1.05	0.75	33	8/31
	-	0.07	1.07	0.72	32	8/31
	-	0.07	1.01	0.76	33	8/31
	-	0.05	0.99	0.46	36	
	-	0.07	0.96	0.57	36	
	-	0.07	1.00	0.71	36	
	-	0.07	1.00	0.67	36	
NYCC	-	2.6	2.0	0.63	18	
	1.23	3.34	1.97	0.58	17.9	10/9
	1.36	3.21	2.02	0.58	15.4	10/9
CUE	-	0.30	0.93	0.33	35	

TABLE A-2. TEST DATA, FIAT 131 DIESEL
CATALYST/EUROPEAN FUEL

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	g/mi	g/mi	MPG	Date/Comments
FTP Bag 1	0.29	0.42	1.18	1.45	25	9/13
Bag 2	0.44	0.67	1.15	1.80	30	9/13
Bag 3	0.25	0.33	1.07	1.19	30	9/13
Composite	0.36	0.52	1.13	1.55	29.1	9/13
FTP Bag 1	0.49	0.60	1.15	3.32	24	9/12
Bag 2	0.49	0.61	1.1	0.36	30	
Bag 3	0.25	0.40	1.07	0.81	30	
Composite	0.42	0.55	1.10	1.12	28.7	
Bag 1	0.31	0.41	1.13	2.94	27	9/14
Bag 2	0.46	0.93	1.23	2.1	30	
FTP Bag 1	0.32	0.49	1.26	-	21.5	10/11
Bag 2	0.43	0.75	1.19	-	24.5	10/11
Bag 1	0.32	0.37	0.66	1.3	24.5	10/12 Filter plugged
Bag 2	0.46	1.21	1.03	0.59	31.9	10/12-3
Bag 3	0.33	0.49	0.86	1.15	28.8	10/12
WEIGHTED	0.40	0.84	0.91	0.86	29.2	
Bag 1(Hot Start)	0.15	0.32	0.73	-	40.4	10/10
Bag 2	0.28	0.79	1.08	-	29.6	
15 mph, 1st gear	0.54	0.93	1.98	1.27	15.7	10/10
25 mph, 2nd gear	0.31	0.37	1.20	0.63	25.8	10/10
	0.29	0.35	1.25	0.44	24.4	10/10
40 mph, 3rd gear	0.15	0.10	0.78	0.42	42	
	0.18	0.11	0.76	0.48	41	
50 mph, 4th gear	0.06	0.04	0.84	0.37	40	
	0.09	0.04	0.85	0.39	37	
	0.10	0.05	0.86	0.73	38	
50 mph, 5th gear	0.12	0.04	0.93	1.01	34.9	10/10
	0.13	0.04	0.98	0.86	33.5	10/10
60 mph, 5th gear	0.16	0.04	1.03	2.15	35	
	0.17	0.04	1.04	1.95	35	

TABLE A-3. TEST DATA, FIAT 131 NA DIESEL
CATALYST/EPA FUEL

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	g/mi	g/mi	MPG	Date/Comments
FTP Bag 1	0.24	0.58	1.00		23.8	1/30 80-21
Bag 2	0.33	0.63	0.91		29.3	1/30 -21
Bag 3	0.41	0.55	0.89		29.6	1/30 -22
Bag 4	0.49	0.80	0.99		27.7	1/30 -22
WEIGHTED AVE.	0.38	0.64	0.95	0.42	27.7	
Bag 1	0.41	0.52	1.13	-	21.8	2/1 -25
Bag 2	0.92	0.66	1.14	-	24.0	2/1 -25
Bag 3	0.39	0.41	1.06	-	26.1	2/1 -25
WEIGHTED AVE.	0.67	0.56	1.12	-	24.0	2/1 -25
Bag 1	0.51	0.49	1.10	0.39	22.8	2/1 -30
Bag 2	1.19	0.81	1.14	0.79	23.8	2/1 -30
Bag 3	0.51	0.45	1.05	0.63	25.9	2/1 -30
WEIGHTED AVE.	0.86	0.65	1.11	0.66	24.1	2/1 -30
Bag 1	0.46	0.51	0.98	0.78	26.1	2/4 -35
Bag 2	0.54	0.60	1.06	0.38	27.4	2/4 -35
Bag 3	0.40	0.40	0.93	0.51	29.4	2/4 -35
WEIGHTED AVE.	0.48	0.53	1.01	0.50	27.7	2/4 -35
15 MPH, 1st gear	1.35	2.05	1.28	1.09	17.0	2/5 -40
	1.74	3.25	1.26	1.37	17.2	2/5 -41
25 MPH, 2nd gear	1.59	1.21	0.90	0.71	25.8	2/1 -31
	1.06	2.72	0.92	0.60	26.7	2/1 -32
40 MPH, 3rd gear	0.27	0.13	0.79	0.46	28.8	2/1 80-26
	0.31	0.11	0.78	0.37	29.2	2/1 -27
50 MPH, 4th gear	0.14	0.04	0.84	0.44	31.4	2/1 -28
	0.13	0.04	0.84	0.43	31.9	2/1 -29
50 MPH, 5th gear	0.08	0.04	0.75	0.33	41.7	2/4 -36
	0.07	0.04	0.75	0.34	43.4	2/4 -37
60 MPH, 5th gear	-	0.04	1.02	0.33	29.2	2/5 -42
	0.10	0.04	1.02	0.56	29.2	2/5 -43
HIGHWAY	0.11	0.04	0.86	-	33.6	1/31 -23
	0.14	0.08	0.85	-	32.8	1/31 -23
	0.08	0.04	0.84	0.45	34.3	2/5 -44
	0.12	0.05	0.85	0.52	31.8	2/5 -45

TABLE A-3. TEST DATA, FIAT 131 NA DIESEL
CATALYST/EPA FUEL (CONTINUED)

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	g/mi	g/mi	MPG	Date/Comments
NYCC	1.82	3.67	1.98	0.71*	13.4	1/29 -20
(hot start)	1.45	3.36	2.03	0.71*	13.9	1/29 -20
	1.14	2.20	1.73	1.18	14.1	2/6 -46
	1.51	3.05	1.72	0.83	14.1	2/6 -47
NYCC	0.53	4.39	2.15	0.79*	11.0	1/28 -18
(cold start)	2.90	4.36	2.53	0.79*	10.2	1/29 -19
CUE	0.17	0.13	0.85	0.52	34.8	2/5 -39
	0.11	0.20	0.90	0.46	29.0	1/31 -24

*average of 2 runs

TABLE A-4. TEST DATA, FIAT 131 DIESEL NO CATALYST/EPA FUEL

CYCLE	EMISSIONS HC g/mi	CO g/mi	NO_x g/mi	PARTICULATE g/mi	FUEL ECONOMY MPG	Date/Comments	
FTP Bag 1	0.53	1.66	1.61	-	25.8	10/12-1	
Bag 2	0.44	2.06	1.72	-	27.2	10/12-3	
Bag 3	0.45	1.57	1.47	-	27.9	10/12-4	
WEIGHTED	0.46	1.83	1.62	-	27.1		
Bag 1	0.49	1.67	1.54	0.46	25.3	10/25	79-26
Bag 2	0.42	1.84	1.49	0.31	29.2		-27
Bag 3	0.45	1.27	1.37	0.51	30.4		-28
WEIGHTED	0.44	1.64	1.47	0.40	28.7		
Bag 1	0.52	1.74	1.66	0.58	23.1	10/26	-34
Bag 2	0.43	2.01	1.84	0.32	24.9		-35
Bag 3	0.57	1.49	1.49	0.54	27.6		-36
WEIGHTED	0.50	1.80	1.70	0.44	25.3		
Bag 1 Hot	0.48	1.42	1.30	-	27.1	10/30	-52
Bag 2	0.36	1.83	1.62	-	27.7		
Bag 1	0.59	1.73	1.54	-	24.3	10/31	-67
Bag 1	0.36	1.76	1.60	-	23.3	10/29	-38
Bag 2	0.33	1.93	1.69	-	25.8	10/29	-39
Bag 1 Hot	0.31	1.44	1.48	-	23.7	10/29	-40
Bag 2	0.23	1.87	1.65	-	30.0	10/29	-41
15 MPH, 1st gear	0.70	3.39	2.49	0.58	17.4	11/1	-84
	1.22	5.41	2.35	0.85	16.5	11/2	-89
	1.05	4.84	2.47	0.60	16.4	11/2	-96
25 MPH, 2nd gear	0.54	1.98	1.49	0.40	28.9	11/1	-86
	0.71	2.94	1.39	0.50	25.4	11/2	-91
	0.75	3.03	1.42	0.38	25.6	11/2	-93
	0.65	2.80	1.43	0.65	30.7	12/10	-102
	0.64	2.73	1.46	-	29.6		-106
40 MPH, 3rd gear	0.39	0.97	1.23	0.41	34.7	11/1	-81
	0.42	1.02	1.21	0.39	34.0	11/1	-85
50 MPH, 4th gear	0.40	0.79	1.21	-	36.0	12/11	-107
	0.30	0.58	1.15	0.38	38.0	11/1	-82
	0.38	0.71	1.22	0.50	36.6	11/2	-90
	0.57	0.76	1.17	0.56	35.8	11/2	-94
	0.41	0.72	1.06	0.49	43.5	12/10	-103
	0.41	0.77	1.23	-	36.6		-113

TABLE A-4. TEST DATA, FIAT 131 DIESEL
NO CATALYST/EPA FUEL (CONTINUED)

	EMISSIONS						
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY		
CYCLE	g/mi	g/mi	g/mi	g/mi	MPG	Date/Comments	
50 MPH, 5th gear	0.36	0.58	1.11	0139	38.2	11/1	-87
	0.60	0.63	1.15	0.66	38.8	11/2	-92
60 MPH, 5th gear	0.40	0.43	0.30	0.47	33.2	11/1	-83
	0.52	.50	1.40	0.63	31.2	11/1	-88
	0.74	0.59	1.27	0.80	30.9	11/2	-95
HIGHWAY	0.33	0.73	1.35	0.45	32.1	10/25	
	0.34	0.72	1.32	0.48	33.2	10/25	
	0.39	0.74	1.36	0.45	32.7	10/25	
	0.33	0.76	1.25	0.40	32.3	10/29	79-42
	0.36	0.78	1.18	0.33	28.7	10/29	-43
	0.32	0.74	1.18	0.29	28.6	10/29	-44
	0.34	0.76	1.18	0.24	28.7	10/29	-45
	0.35	0.78	1.32	0.25	30.7	10/29	-46
	0.37	0.78	1.11	0.24	28.6	10/29	-47
	0.32	0.78	1.15	--	31.1	10/29	-48
	0.31	0.83	1.15	0.26	30.2	10/29	-49
	0.42	0.80	1.16	0.50	32.6	10/30	-54
	0.34	0.74	1.16	0.31	33.4	10/30	-55
	0.36	0.76	1.18	0.36	32.8	10/30	-56
	0.38	0.78	1.29	0.45	32.3	10/30	-58
	0.32	0.71	1.25	0.45	32.3	10/30	-59
	0.36	0.75	1.19	0.41*	33.7	10/30	-60
	0.32	0.73	1.20	0.41*	32.5	10/30	-61
	0.36	0.77	1.19	0.42*	31.7	10/30	-62
	0.33	0.73	1.20	0.42*	31.9	10/30	-63
	0.38	0.77	1.19	0.46*	31.0	10/30	-65
	0.37	0.75	1.20	0.46*	31.2	10/30	-66
	-	0.80	1.14	0.47*	32.0	10/30	-69
	0.38	0.65	1.10	0.47*	34.9	10/31	-70
	0.35	0.73	1.07	0.41*	33.9	10/31	-71
	0.32	0.70	1.09	0.41*	34.1	10/31	-72
	0.35	0.74	1.13	0.42*	32.0	10/31	-73
	0.32	0.71	1.19	0.42*	32.2	10/31	-74
	0.33	0.74	1.07	0.41*	31.2	10/31	-75
	0.32	0.72	1.03	0.41*	32.1	10/31	-76
	0.36	0.81	1.11	0.45*	30.9	10/31	-77
	0.36	0.73	1.05	0.45*	31.3	10/31	-78

*Average Valu? (particulate collection combined)

TABLE A-4. TEST DATA, FIAT 131 DIESEL
NO CATALYST/EPA FUEL

	EMISSIONS						
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY		
CYCLE	g/mi	g/mi	g/mi	g/mi	MPG	Date/Comments	
HIGHWAY - shift into 5th gear at 45 MPH	0.24	0.57	1.10	-	39.4	10/26	-37
	0.33	0.83	1.26	0.43*	36.8	12/11	-100
	0.31	0.79	1.19	-	37.8	12/11	-101
	0.32	0.78	1,08	-	37.4	12/12	-111
NYCC (cold)	0.93	4.21	2.36	0.81	15.8	10/17	
	1.36	5.00	3.27	0.96	12.0	12/11	79-99
	1.34	5.21	2.93	-	12.6	12/12	-110
NYCC (hot)	0.88	3.94	2.49	0.50*	13.8	10/31	-79
	1.04	4.12	2.62	0.50*	14.5	10/31	-79
	1.12	4.15	2.57	0.47*	13.0	10/31	-80
	1.10	4.31	2.58	0.47*	12.9		
Sulfate Cycle (CUE)	0.42	1.04	1.46	0.45	31.1	10/25	
	0.37	1.00	1.40	0.45	31.3	10/25	
	0.44	1.17	1.50	0.29	28.9	10/30	-57
	0.43	1.05	1.15	0.57	38.4	12/10	-105
	0.42	1.13	1.33	-	34.0	12/11	-109

*Average Value (particulate collection combined)

TABLE A-5. TEST DATA, FIAT 131 DIESEL NO CASTALYST/EUROPEAN FUEL

	EMISSIONS						
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY		
CYCLE	g/mi	g/mi	g/mi	g/mi	MPG	Date/Comments	
FTP Bag 1	0.46	1.66	1.56	-	24.4	1-2	80-1
Bag 1	0.37	1.44	1.02	-	24.8	1-3	-12
Bag 2	0.47	1.68	1.13	-	28.8	1-3	-12
Bag 1 Hot Start	0.48	1.39	0.90	-	30.[illegible]	12-20	79-135
Bag 2	0.41	1.71	1.04	-	28.6	12-20	-136
Bag 1 Hot Start	0.36	1.34	1.33	-	27.8	1-2	80-3
Bag 2	0.37	1.74	1.47	-	26.2	1-2	-4
Bag 1 Hot Start	0.38	1.23	0.88	-	30.0	1-3	-113
Bag 2	0.41	1.62	1.05		27.1	1-3	-113
Bag 1 & 2				0.41		1-2	80-1/2
				0.59		1-3	-12
Bag 1 & 2 Hot Start				0.34		12-20	79-135/6
				0.54		1-2	80-3/4
				0.51		1-3	-13

TABLE A-5. TEST DATA, FIAT 131 DIESEL
NO CATALYST/EUROPEAN FUEL (CONTINUED)

	EMISSIONS						
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY		
CYCLE	g/mi	g/mi	g/mi	g/mi	MPG	Date/Comments	
15 MPH, 1st gear	1.16	4.18	2.30	1.16	17.4	12-18	79-124
	1.13	4.07	2.23	1.01	15.8	12-18	-125
	0.76	4.17	2137	1.58	16.8	12-19	-130
25 MPH, 3rd gear	0.35	0.97	1.22	0.5[illegible]	36.7	12-17	-114
	0.35	0.86	1.18	0.55	38.4	12-17	-115
	0.54	1.13	1.16	0.55	33.5	12-18	-127
50 MPH, 4th gear	0.32	0.65	1.14	0.34	34.0	12-18	-122
	0.34	0.71	1.07	0.44	35.0	12-18	-123
	0.41	0.72	1.09	0.58	34.5	12-18	-128
50 MPH, 5th gear	0.37	0.57	1.07	0.61	41.6	12-17	-118
	0.35	0.58	1.11	0.51	42.0	12-17	-119
	0.23	0.63	1.04	0.52	39.0	12-19	-132
50 MPH, 5th gear	0.55	0.48	1.27	0.65	35.4	12-17	-120
	0.43	0.49	1.25	0.61	31.0	12-17	-121
	0.49	0.58	1.24	0.68	30.6	12-18	-129
	0.38	0.55	1.23	0.69	30.0	12-19	-131
HIGHWAY ≤ 4th gear	0.36	0.62	1.13	2.1	35.0	10-16	79-17
	0.27	0.57	1.12	1.8	35.9	10-16	-18
	0.26	0.79	1.37	0.40*	32.1	4-1	80-49
	0.26	0.77	1.32	0.40*	33.9	4-1	-49
HIGHWAY shift into 5th gear at 45 MPH	0.32	0.74	1.11	0.10*	32.9	1-2	80-5
	0.28	0.73	1.09	0.10*	32.4	1-1	-6
	0.19	0.71	1.08	0.12*	31.6	1-2	-7
	0.28	0.70	1.09	0.12*	31.6	1-2	-8
	0.27	0.86	1.26	0.35*	34.7	4-1	-50
	0.24	0.83	1.19	0.35*	36.7	4-1	-50

*Average Value (particulate collection combined)

TABLE A-5. TEST DATA, FIAT 131 DIESEL
NO CATALYST/EUROPEAN FUEL (CONTINUED)

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	g/mi	g/mi	MPG	Date/Comments
NYCC	0.48	3.59	2.53	0.40*	13.5	1-2 80-10
	0.75	3.67	2.50	0.40*	13.6	1-2 -10
	0.54	3.77	1.59	0.49*	15.2	1-3 -14
	0.54	3.51	1.58	0.49*	16.0	1-3 -14
	0.52	3.54	1.60	0.49*	15.8	1-3 -14
	0.52	3.70	1.61	0.49*	13.5	1-3 -14
CUE	0.28	1.04	1.23	0.46	31.5	1-2 -9

*Average Value (particulate collection combined)

TABLE A-6. FIAT 131 NA LARGE VOLUME PARTICULATE SAMPLES

CYCLE	CATALYST EUROPEAN FUEL	NO CATALYST EUROPEAN FUEL	CATALYST EPA FUEL	NO CATALYST EPA FUEL
FTP URBAN				
BAGS 1 + 2	4.55	2.44	0.92	1.26
BAGS 3 + 4	1.49	1.93	0.64	1.19
HIGHWAY	2.21	4.89	2.43	34.00
CUE (Sulfate)	8.58	1.50	1.52	1.53
NYCC	2.09	1.32	1.60	1.06
NYCC (cold start)	0.95	0.93	1.77	--

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